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Health and Environmental Effects of Oil Shale Technology: A Workshop Summary and Panel Reports

MITRE Corp, McLean, VA METREK Div

Prepared for

Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies, McLean, VA

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Health and Environmental Effects of Oil Shale Technology

A Workshop Summary and Panel Reports

for the

Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies

Department of Energy

Department of Health,
Education, and Welfare

Environmental
Protection Agency

Executive Secretariat
The MITRE Corporation / Metrek Division
McLean, Virginia 22102

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This report responds to President Carter's directive to identify health and environmental problems associated with advanced energy technologies. The report contains a presentation of the highlights of the issues and the detailed information requirements identified by panels of a workshop held in Denver, Colorado in April 1978 to address the health and environmental effects of oil shale technology.

The purposes of this workshop were to: 1) assemble multidisciplines of biomedical and environmental scientists to address current developments in these technologies, 2) review and identify specific health and environmental issues and problems associated with their development and commercialization, and 3) consider research strategies required to address them and to identify requisite information needs for resolving uncertainties of assessing the relevant impacts of oil shale technologies.

The six panels of the workshop were: health effects; air quality; water quantity, quality, and aquatic ecology; terrestrial effects; ambient measuring and monitoring; and source characterization. Panel reports containing specific information on environmental and health effects, information requirements, and detailed research statements are included in this report.

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A Workshop Summary
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Edited by:
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May 1979

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Metrek Division

Executive Secretariat
The MITRE Corporation/Metrek Division
1820 Dolley Madison Boulevard
McLean, Virginia 22102

FOREWORD

In his 1977 Environmental Message, President Carter directed the Secretary of Energy, the Secretary of Health, Education, and Welfare, and the Administrator of The Environmental Protection Agency to establish a joint program to identify the health and environmental problems associated with energy technologies and to review the adequacy of present environmental research programs. In response to the President's directive, representatives of the three Agencies formed the Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies. The MITRE Corporation, Metrek Division, is the Executive Secretariat for the Committee.

The goals of this Committee are to review and identify specific health and environmental issues and potential problems associated with the development and commercialization of conventional and advanced energy technologies, to identify the research information required to resolve the uncertainties of assessing relevant impacts, to specify research projects to provide such information, and to review the adequacy of current Federal research with respect to these projects. To attain these goals, the Committee is sponsoring a series of workshops, establishing working groups, and initiating other approaches to address the health and environmental consequences of specific energy technologies.

This report is the result of a workshop which addressed the health and environmental effects of oil shale technology in Denver, Colorado, April 16-20, 1978 chaired by George Shepherd of the Department of Energy. MITRE technical support for workshop activities and preparation of this report has been provided under joint funding by the Committee through a Department of Energy contract mechanism (DEAC-01-79-EV10018), MITRE project number 1686J.

The purposes of this workshop were:

- to assemble biomedical and environmental scientists, representative of a broad range of disciplines, to address current developments in oil shale technology
- to review and identify specific health and environmental issues and problems associated with the development and commercialization of oil shale technology
- to consider the research strategies required to address them and to identify the requisite research information needs, expressed via detailed task statements, for resolving the uncertainties of assessing the relevant impacts of oil shale technology.

Throughout the workshop, attendees participated in six panels: health effects; air quality; water quantity, quality, and aquatic ecology; terrestrial effects; ambient measuring and monitoring; and source characterization. This report contains a presentation of the highlights of the issues considered by the panels and the panel reports which contain specific information on environmental and health effects, information requirements, and detailed research statements. Lists of workshop participants, and support staff are provided in the Appendix.

This report on oil shale technology responds to the first part of the President's directive--to identify health and environmental problems. The requisite research information needs associated with these problems will be compared with present Federal research programs in another report, a synthetic fuels summary, which will relate the priority of health and environmental research requirements for oil shale and coal gasification and liquefaction to ongoing research. The result of this comparison and other products of the Interagency Committee should provide a basis for strengthening the Federal program for ensuring safe and timely development of our energy resources.

THE FEDERAL INTERAGENCY COMMITTEE
ON THE HEALTH AND ENVIRONMENTAL
EFFECTS OF ENERGY TECHNOLOGIES

HEALTH AND ENVIRONMENTAL EFFECTS OF OIL SHALE TECHNOLOGY

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*Committee membership as of April 1978.

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HEALTH AND ENVIRONMENTAL EFFECTS OF OIL SHALE TECHNOLOGY

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The efforts of a large number of individuals were instrumental in the successful completion of the workshop, panel reports and document. Members of the Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies provided valuable guidance and comments. Janet Buckwalter and Adeline Normandy provided invaluable secretarial support during the workshop. Sylvia Halpern and Marion Meader contributed to preworkshop coordination. Substantial contributions to the preparation of the basic panel reports were made by the following persons: Judith Hushon (Health Effects), Edward Ward (Air Quality), Ali Ghovanlou (Ambient Measuring and Monitoring), Peter Haug (Terrestrial Effects), Alexis Taylor (Water Quantity, Quality, and Aquatic Ecology), and James Antizzo (Source Characterization). Technical background materials for use at the workshop were prepared by Howard Williams. Victor Wenk provided overall coordination and interface among contributing parties during the workshop. Richard Brown was responsible for the compilation of panel reports and preparation of this report. A special thank you is given to Ruth Cooke, who provided invaluable logistics support in arranging the workshop and coordinating follow-up activities. Acknowledgement is given to the workshop chairmen who contributed numerous hours of workshop coordination, report preparation, review, and revision.

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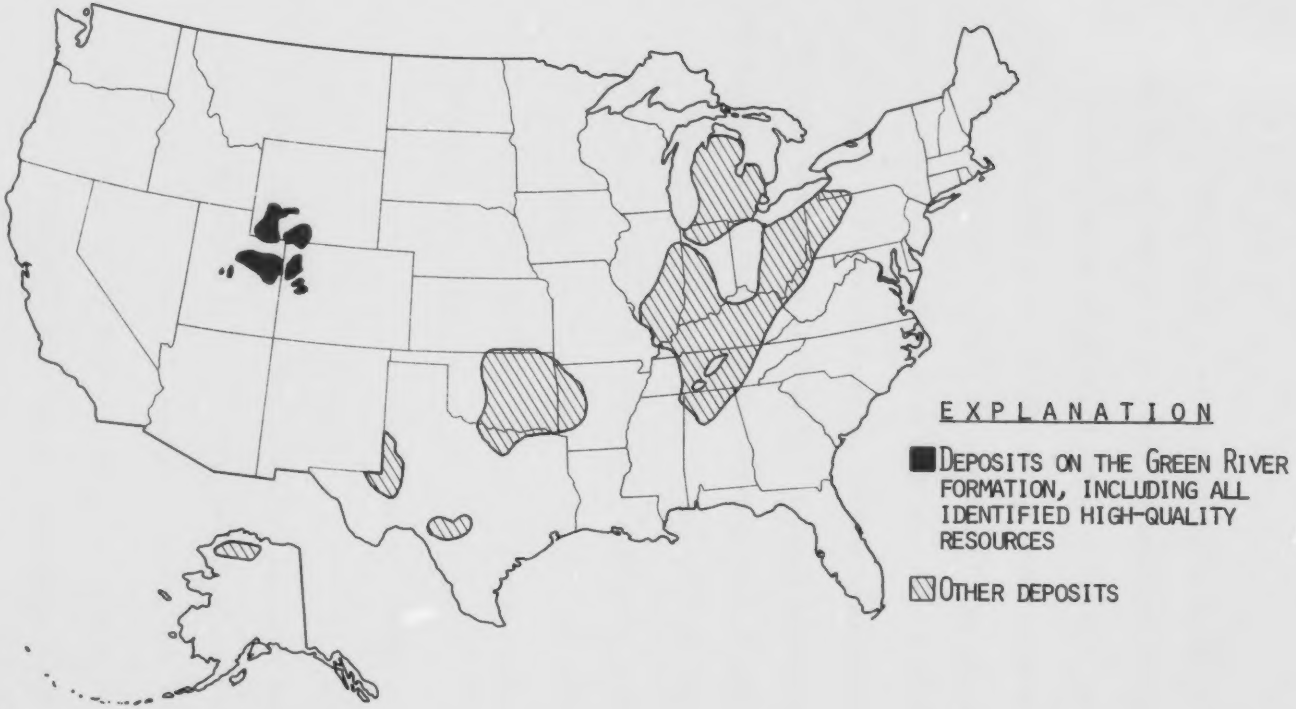
INTRODUCTION

The Resource

Oil shale is a fine-grained, grey brown, sedimentary rock containing kerogen, a powdery substance yielding a synthetic oil and gas after pyrolysis or retorting. The high-grade deposits of the Colorado-Wyoming-Utah area known as the Green River Formation can yield 25 or more gallons of oil per ton of shale. Colorado's Piceance Basin contains 85 percent of the Western high-grade shale in beds from 10 to 2,000 feet thick. Low-grade, shallow deposits underlie large parts of the Eastern and Central states and northern Alaska (Figure 1). The U.S. Department of the Interior has estimated that 80 billion barrels of oil can be recovered from the beds of Western oil shale using current technology. This is more energy than is contained in known U.S. oil and natural gas reserves, and only about one-tenth of the estimated 800 billion barrels of shale oil that may be recoverable using more advanced technology and under different economic conditions.

The Technology

Shale oil can be produced from oil shale by three types of retorting processes: surface, true in situ, and modified in situ. In each case, the oil shale must be heated (retorted) to 400°C, or higher to bring about pyrolysis of the kerogen and production of shale oil or gas. The process used to produce the synthetic fuel depends on the depth, composition, and geographic location of the


EXPLANATION
■ DEPOSITS ON THE GREEN RIVER FORMATION, INCLUDING ALL IDENTIFIED HIGH-QUALITY RESOURCES
▨ OTHER DEPOSITS

SOURCE: Duncan, D.C., and V.E. Swanson 1965 Organic-Rich Shale of the United States and World Land Areas, U.S. Geological Survey Circular 523. Washington: Government Printing Office.

FIGURE 1
PRINCIPAL REPORTED OIL SHALE DEPOSITS OF THE UNITED STATES

shale formation or deposit, and the technological, economic, and environmental tradeoffs. The produced oil and gas can be transported, refined, and used like conventional oil and gas (Figure 2).

Surface processes require the mining of oil shale by either underground or surface methods. Following extraction the oil shale is crushed and sized before retorting. After retorting, 85 percent of the total weight of the shale remains as spent shale, which can be used as fill material, because it essentially has no market value.

Surface-retorting processes utilize either a direct or an indirect method to heat the oil shale. Creating a combustion zone within the retort supplies the required heat for pyrolysis of the kerogen in the direct method. The combustion is sustained by gases released from the heated oil shale. In the indirect method gases are circulated in an external reactor or combustor, and heat is transferred to the retort by recirculating solids or the gases through the retort and the external reactor. The products and residuals from these two methods for producing oil and gas differ somewhat in their chemical properties.

True in situ processes involve underground retorting with no mining or disposal of retorted oil shale. This technology will be more applicable to shales found in relatively thin beds at various depths. The oil shale formation is first fractured (using a hydraulic explosive fracturing technique) to provide the necessary surface area and permeability for combustion and thermal conduction. The oil

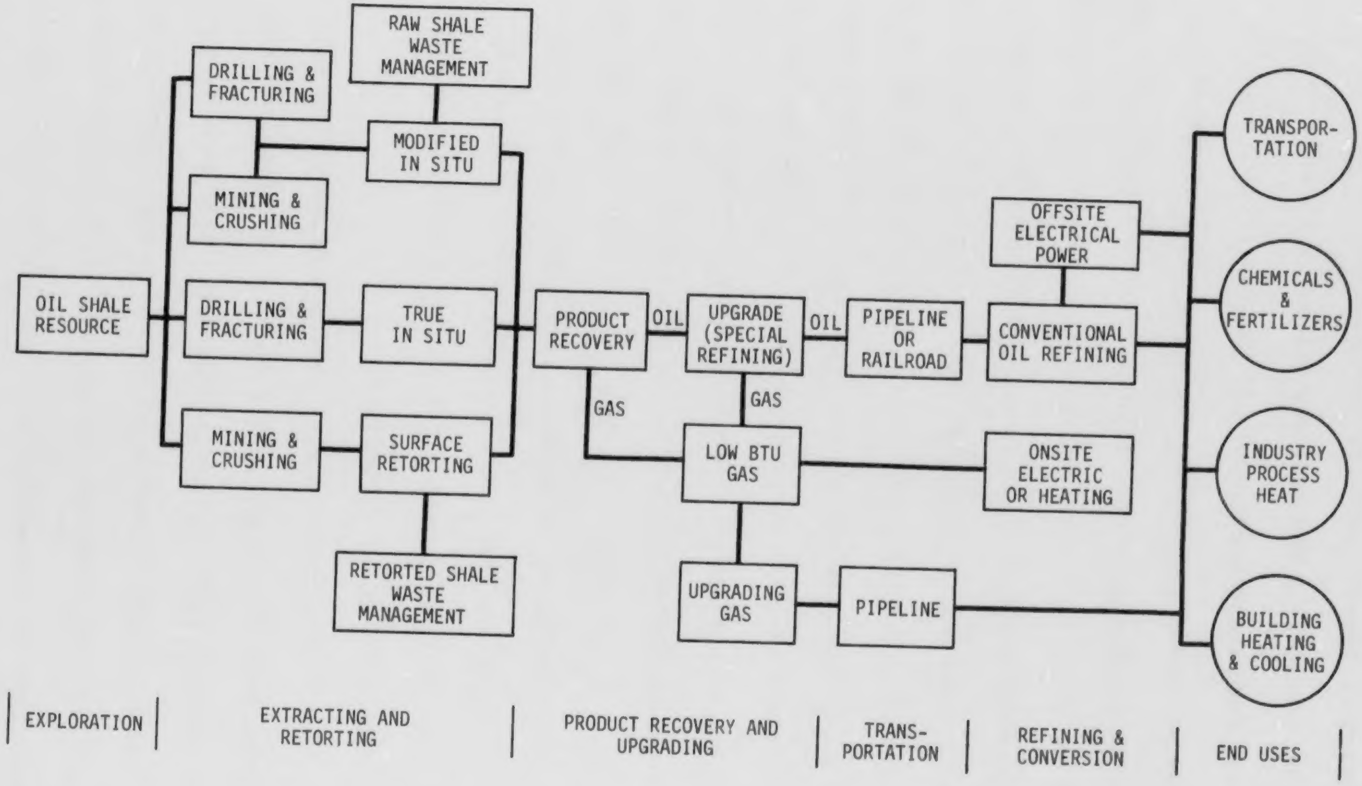

OIL SHALE RESOURCE
DRILLING & FRACTURING
MINING & CRUSHING
DRILLING & FRACTURING
MINING & CRUSHING
RAW SHALE WASTE MANAGEMENT
MODIFIED IN SITU
TRUE IN SITU
SURFACE RETORTING
RETORTED SHALE WASTE MANAGEMENT
PRODUCT RECOVERY
OIL
GAS
UPGRADE (SPECIAL REFINING)
OIL
GAS
LOW BTU GAS
UPGRADING GAS
PIPELINE OR RAILROAD
PIPELINE
OFFSITE ELECTRICAL POWER
CONVENTIONAL OIL REFINING
ONSITE ELECTRIC OR HEATING
TRANSPOR-TATION
CHEMICALS & FERTILIZERS
INDUSTRY PROCESS HEAT
BUILDING HEATING & COOLING
EXPLORATION
EXTRACTING AND RETORTING
PRODUCT RECOVERY AND UPGRADING
TRANS-PORTATION
REFINING & CONVERSION
END USES

FIGURE 2
SHALE FUEL CYCLE

shale is then ignited via a central injection well, and combustion is sustained by pumping compressed air into the injection well. Produced gases and liquids are forced or pumped horizontally through the fracture system to production wells which surround the injection well.

The modified in situ process involves mining about 10 to 30 percent of the shale to increase the void volume for in situ retorting. The remaining oil shale (directly above the mined zone) is fractured rubblized, and retorted in place. Retorting in the modified in situ process can be performed either by forcing the combustion zone to move horizontally for thin shale deposits or vertically for thick deposits. The mined-shale fraction is processed in a surface retort.

Shale oil from a retorting process passes through a product-recovery stage involving the separation and recovery of the oil or gaseous products from contaminants, which include water produced in the retorting process as well as particulate material. Following recovery, the product is upgraded by removal of nitrogen compounds and treated to improve flow characteristics. During processing of the oil shale, low-Btu gas is produced concurrently with the shale oil. The low-Btu gas can be used onsite for heating or the production of electricity, or it can be upgraded to pipeline gas for use elsewhere. Gas is expected to be the primary product of the Eastern deposits.

The upgraded shale oil can be transported for processing in conventional refineries. The treated shale oil or its products can then be used for electrical power generation, heating, transportation, or as petrochemical feedstocks similar to conventional crude oil.

Stage of Development

Shale oil is not currently in commercial production in the U.S. Recorded evidence suggests that production has occurred on a relatively small scale from time to time in 13 foreign countries since 1350. Only two significant industries exist today--in Manchuria and Estonia. Since 1850, a U.S. oil shale boom appeared imminent but never materialized, because more economical oil supplies became available with the development of domestic oil fields. However, with U.S. petroleum supplies dwindling and the price of world oil increasing, major advances in shale oil recovery technology are taking place.

In recent years, three kinds of hot-gas retorting processes have become sufficiently well developed to be ready for installation in commercial-scale plants. The first, a Paraho Development Corporation facility near Rifle, Colorado produced 100,000 barrels of shale oil that was refined in December 1978 into various fuels. This project, under contract with the U.S. Navy, is an outgrowth of a demonstration program based on a design used for many years to process limestone. For the second process, Union Oil Company has developed plans, based on pilot plant studies, for the operation of a vertical gas-recycle retort process in a 50,000-barrels-a-day plant located in Colorado. The Superior Oil Company plans to utilize a unique, circular gas-combustion retort in which the shale travels horizontally through the retorting zone. Superior intends to use this retort on its own shale properties in Colorado. The dawsonite and nahcolite contained in this shale can be recovered as part of the shale oil processing sequence. The third type consists of the heated-solids retorting methods, two of which are considered ready for commercial operation. The Lurgi-Ruhrgas process, a modified German coal carbonization technique developed in the 1950s, uses sand or recycled shale ash to retort raw shale crushed to a fineness of less than one-half inch. The TOSCO II retort process, based on a Swedish design, uses small preheated ceramic balls to transfer heat to finely crushed oil shale. Based on this process, a commercial-size plant has been designed to produce 47,000 barrels a day of shale oil and 4,300 barrels a day of liquefied petroleum gas (LPG).

In addition, several types of in situ processes are considered almost ready for commercial development. The Occidental Oil Company and Ashland Oil are conducting evaluation tests prior to the construction of a full-scale "modified" in situ commercial facility. The first retort at the Colorado site is expected to be ready for processing in late 1980. In 1983, full production (40 retorts) is expected to reach a rate of 57,000 barrels daily.

The Laramie Energy Technology Center (LETC) of the Department of Energy is planning modified in situ experiments which include the retorting of shale beds of varying depth and thickness with some portion of the shale removed prior to explosive fracturing of the beds. A project performed by Geokinetics will involve relatively shallow thin shale beds and will produce a surface disturbance (upheaval) following fracturing. Another project performed by Equity Oil involves injection of superheated steam into thick, deep, leached shale beds and may include recovery of other minerals.

The true in situ projects include LETC experimental oil shale sites (200-foot depths) at Rock Springs and a pending Talley-Frac project near Rock Springs. The Talley-Frac project is a scale-up of the LETC Rock Springs experiments.

RESEARCH HIGHLIGHTS

This summary is a brief condensation of the major problems identified in the six panel reports. The reports, encompassing over 200 pages, describe numerous problems and research tasks:

Panel Report	Number of Problems	Number of Research Tasks
Health Effects	25	68
Air Quality	7	21
Water Quantity, Quality and Aquatic Ecology	17	61
Terrestrial Effects	25	44
Ambient Measuring and Monitoring	10	41
Source Characterization	10	55
Total	94	290

In addition to problems and research tasks, descriptions of health and environmental effects and information needs are presented. This summary focuses on the highlights of the panel reports pertinent to the oil shale industry. The reader is referred to the individual panel reports for details regarding problem statements, data requirements, and specific research tasks.

Concerns

The major health and environmental impact areas within the oil shale energy cycle are presented in Table I. Concern for occupational health and safety is evident in all phases of the technology. Workers can be exposed to a wide variety of pollutants in gaseous, liquid, and solid form which are associated with the various stages of the oil shale energy cycle described in Figure 2. The gaseous emissions consist of criteria pollutants, trace elements, light hydrocarbons, sulfur and nitrogen compounds, polycyclic organic matter, and radionuclides. The liquid effluents consist of hydrocarbons, phenols, trace elements, salts, suspended solids, oil, sulfides and ammonia, polycyclic organic matter, and radionuclides. Finally, the solids include shale fines, spent shale, and spent chemicals.

Health effects research should place emphasis on the detection of occupational health effects as they may serve as indicators of more subtle health effects, in the general population. Safety concerns center on the structural integrity of in situ retorts and room and pillar mines. Explosions and fires can result from combustion of fugitive dust and volatile hydrocarbons at several stages in the fuel cycle. As in other extractive and processing industries, hazards to the worker in the form of heat, pressurized equipment, electrical devices, and loud sounds also exist.

Human health concerns with respect to food supplies, drinking water, and air quality and environmental concerns stem from the

TABLE I

MAJOR HEALTH AND ENVIRONMENTAL CONCERNS IN THE OIL SHALE ENERGY CYCLE

	PLANNING & DEVELOPMENT	EXTRACTION			CONVERSION			UTILIZATION		
	Mine and Retort Construction	Shale Extraction	Crushing, Grinding	Storage & Handling	Retorting	Upgrading	Waste Disposal	Storage	Final Upgrading and Distribution	Consumption
PHYSICAL										
Air Quality	●	●	●	●	●	●	●			●
Water Quality	●	●	●	●	●	●	●			
Water Supply	●	●	●		●	●	●			
Land Disturbance	●	●					●			
Subsidence		●								
Noise	●	●	●		●					
BIOLOGICAL										
Aquatic	●	●			●		●			
Terrestrial	●	●			●		●			
SOCIETAL										
Occupational Health & Safety	●	●	●	●	●	●	●	●	●	●
Public Health & Safety					●	●	●			●

effects on air and water quality and biota. These effects are associated with airborne emissions of fugitive dust and gases, and contaminated water effluents in the form of leachates from waste disposal sites and surface water or groundwater runoff. Many of these emissions and effluents may contain toxic trace metals and organic compounds.

Alteration of land and water regimes can occur through the disposal of spent shale from surface-retorting operations. Toxic metals and potentially carcinogenic organic compounds may be present in the spent shale. Land disposal of this waste can produce severe effects on land use and can serve as a source of contamination for surface water and groundwater.

Land reclamation is a problem in waste disposal areas as well as for land disturbed by mining oeprations. Revegetation is a possible solution for land reclamation but has not been demonstrated on a large scale except for strip mining for coal. Although in situ retorting may eliminate many of these problems, groundwater contamination may still occur from toxic residuals which remain underground after completion of in situ retorting. Subsidence from experimental retorts has been small, but careful monitoring will be required for commercial development.

Because most shale oil development is contemplated in water-short regions of Colorado, factual information for water resource assessments is needed. It is known that high water withdrawal rates will be needed for process and cooling water requirements. Although some of the water requirement could be met by reuse of some of the wastewaters, the oil shale industry will have to compete with other water uses in the Colorado River Basin. If the water required to support a large-scale oil shale development is withdrawn from surface waters and not returned, or returned after some evaporation, salinity may increase at a rapid rate because of the concentration of salts in the remaining smaller quantity of water.

After treatment to remove carbonates, most of the ammonia, and some organic material, retort water from surface retorts may be used for wetting the spent shale. Retort water from in situ retorting may require advanced treatment by carbon absorption and ion exchange. If mine dewatering is required during mining or drilling, the saline water removed may require treatment prior to discharge to protect surface or groundwater supplies.

Research Needs

The following summarizes the panels' specific problems and concerns and describes the research needs pertinent to oil shale technology. The various panels focused on different aspects of the health and environmental effects of oil shale technology.

Panel Specific Concerns

The health effects panel assessed the effects of materials associated with oil shale in terms of their hazard potential rather than their toxicity. The panelists voted that the following areas receive primary attention:

1. Identification of effects most likely to result from exposure to oil shale-related materials by surveying the literature on previous epidemiological data
2. Identification of the adequacy of present effluent/emission controls and materials likely to result in human exposure, thereby providing essential guidance for consulting laboratory animal experimentations
3. Analysis of unique safety issues associated with shale mining and in situ retorting
4. Experimentation in laboratories to evaluate effects of materials and mixtures on animals and screening-type studies on large numbers of materials and mixtures.

The terrestrial effects panel identified the following overall research needs:

1. Development of a mechanism to compile review, organize, and synthesize data from completed and ongoing research on oil shale development
2. Integration of information from oil shale technology with information on air and water quality and ecology in a broad framework that considers the interactions within the entire environmental system
3. Development of mathematical models on geology, hydrology, air quality, and ecology to better understand and predict environmental impacts
4. Analysis of biological sensitivity to toxins associated with oil shale technology.

The source characterization panel concluded that research on source characterization should focus on the following areas:

1. Solid wastes disposal, including spent shale, raw shale, catalysts, and chemical sludges
2. Treated process emission and effluent streams
3. Potential surface and groundwater contaminants

4. Trace elements in all process streams

5. Air contaminants as occupational hazards

6. Nitrogen oxide emissions in process streams and from products' use

7. Physical hazards in oil shale mining.

In addition to development of baseline information, the air quality panel identified four problem areas they considered of prime importance. The areas are:

1. Anticipation of increased environmental concentrations of toxic and hazardous materials, particularly the polycyclic organic materials and trace metals, and their impact on human health

2. Anticipation of increased production of photochemical oxidants in the atmosphere having an adverse effect on human health as well as producing stress on vegetation and contributing to visibility degradation

3. The expected inadvertent weather modifications, currently not well defined, associated with the emissions from all cycle components of shale oil development

4. Anticipated degradation of regional visibility from the increased atmospheric loading of primary particulate matter and the production of secondary aerosols.

The water quantity, quality, and aquatic ecology panel focused on the problem areas related to both the quantity and quality of water and the changes in the physical and chemical characteristics of the aquatic environment:

1. The availability and quality of water in streams, alluvial valleys, and bedrock aquifers

2. The legal, environmental, and physical constraints related to withdrawal and use of water

3. The management of water withdrawal in terms of use, distribution, and disposal

4. The management of water quality degradation related to withdrawal, mine refilling, and spent shale disposal

5. The impact of water withdrawal on groundwater levels, spring and stream flows, and aquifer characteristics

6. The impact of plant operations (e.g., in situ retorting and waste water disposal) on the transport of pollutants

7. The effectiveness of controls and monitoring equipment and procedures.

With respect to effects on aquatic organisms, the following major areas were identified:

1. Alterations in water quality resulting from developmental oil shale activities on downstream biota relating to toxicity, bioaccumulation, and degradation of pollutants subject to release and mobilization

2. Biological sampling and monitoring techniques required to assess the ecological effects of oil shale development

3. Baseline monitoring efforts in oil shale development regions

4. Changes in marine and estuarine systems from the use of oil shale products

5. Physical alterations on biota in aquatic habitats

6. The effects on aquatic ecosystems of urban population expansion

Finally, the ambient measuring and monitoring panel identified the following areas not previously covered by the other panels:

1. Development of reliable analytical methods for measuring hazardous emissions both in products, effluents and wastes and in ambient air, water, vegetation, biota, and soil.

2. Development of multicomponent techniques for anions similar to the ones for trace cations

3. Identification of chemical forms in which trace elements occur for adequate understanding of bioavailability and toxicity

4. Development, in the near future, of rapid and continuous methods of analysis, especially for airborne compounds such as polycyclic aromatic hydrocarbons, phenols and aromatic amines

5. Development of improved techniques in the various areas of trace organic analysis for characterizations of constituents in oil shale, retorted shale, and aqueous and gaseous byproducts.

It should be noted that several panels often converge on the same research needs. These needs are grouped into 11 major research areas and are discussed in the following sections.

Major Research Areas

Source Emission Data

Common to all of the problems identified in the workshop in general, is the need for valid source emission data for all components of the energy cycle. Consequently, many research projects address the need for the development of techniques and equipment and the identification of data deficiencies before problems can be placed into proper perspective.

A concern directly related to the assessment of potential health effects associated with oil shale technology is the validity of using source emission data (collected primarily for engineering purposes) from pilot or even bench-scale studies to project pollutant emission rates, ambient concentrations, and effects at the commercial level of development. Since pilot plant operation is essentially the key to both technology and health assessment, the biologist and engineer must work closely together during this phase. Using the basic assumption that the pollutants from the commercial-scale plant can be extrapolated directly from the pilot plant emissions and effluents, the identification and assessment of the biological effects of these pollutants should become the primary focus for research to be validated in the demonstration plants.

Pollutants from Solid Waste

Results from studies relating to solid waste are required by all of the panels. Inevitably, fine particles from piles of discarded waste will reach the air and diminish air quality. Precipitation of these particles on vegetation can have an adverse impact on natural biota. Water contamination from leaching and erosion could adversely affect local use of water by industry, residents, and terrestrial and aquatic organisms in the region.

The source characteriztion panel placed a high priority on the characterization of solid wastes, including spent shale, raw shale, catalysts, and chemical sludges. The panel felt that such characterization should be site and process specific. Information needed includes data on the potential for products emanating from solid waste to degrade air, water, and soil, and options for the treatment and disposal of each type of solid waste.

Of particular importance in the view of the panel was the development of criteria for disposal management in large-scale plant operations. Relating to this problem is the recurring theme that large-scale operations are needed to provide adequate quantities of solid waste to demonstrate waste management techniques. These techniques, as well as permeability studies and leachate characterization should focus on disposal techniques for surface-retorted shales, in situ retorted shales, raw shale, catalysts, and chemical sludges.

Waste shale management was considered by the terrestrial panel to be of high priority. The quantities of raw and processed shale that will be stored for long periods or discarded permanently are comparable (for a single oil shale plant) to the wastes associated with the largest mines in the world. Although some aspects of the management of processed shale have been studied for several years, the remaining critical areas of research identified by the panel include the release, transport, fate, and effects of organic and inorganic substances associated with raw and processed shale and the stabilization, revegetation, and the storage of overburden from open-pit mines.

Airborne dust

Oil shale extraction and processing can be a significant source of dust in the air from blasting, extraction, crushing, grinding, transportation, and storage. The dust particles, which may contain trace elements and organic compounds, can be carried by wind currents to contaminate downwind areas by wet or dry precipitation on land and surface waters. Plants, animals, and humans can be affected through entrapment of inhaled particles, exposure of skin, and the ingestion of contaminated food or water.

The health effects panel placed a high priority on the effects of inhalation of raw and spent shale dust. The effects of dust inhalation may be severe and even more pronounced when combined with the effects (and possible synergistic effects) associated with the inhalation of diesel exhausts, sulfur dioxide, and nitric oxides.

The terrestrial panel regarded effects research on the impact on air quality by fugitive dust from oil shale extraction and conversion processes as a high priority. Emphasis was placed on the need for information relevant to particle-size distribution and chemical composition of the dust.

The source characterization panel agreed that particulate matter and shale dust, as well as combustion gases and methane, may pose health and safety hazards to mine personnel. The panel believed that such emissions can be adequately mitigated by the proper mine design, ventilation, and blasting procedures and that the development and verification of procedures for the unusually large underground shale mines must be accomplished in full-scale opeations.

Trace Elements

Oil shale, like all fossil fuels, contains trace elements which may be mobilized and released to the environment during extraction, processing, and end use of the shale oil and its products. Because oil shale products may be substituted for coal and petroleum products, and because of the vast quantities of shale which are expected to be extracted and processed, the trace elements contained in oil shale are of major concern. These trace elements may be released in air emissions, aqueous streams, or solid wastes. The trace elements are of concern because they may degrade air and water quality, and pose hazards to ecosystems and human health.

The source characterization panel, in addressing these concerns, assigned high priority to research associated with the qualitative and quantitative analysis of trace elements in raw and spent shales, aqueous effluents, and air emissions as a function of processes and process variables. These analyses need to be extended to define the toxic properties of the elements as they relate to humans, flora, and fauna.

The terrestrial panel also focused attention on the need for detailed characterization of trace elements in aqueous effluents as a function of shale source, retort temperature, and operating mode (water and air mixture). The panel identified a need to determine variables which could economically be altered to reduce the mobility of residuals. The panel regarded this topic as a high priority research area in order to determine the biological consequence of the uptake of toxic elements by vegetation growing on spent-shale piles, reclaimed sites, and contaminated areas.

Gaseous Emissions

The health effects and source characterization panels determined that the extraction of shale oil (kerogen) from the raw shale resource involves worker exposure to routine gaseous emissions from both retorting and plant maintenance. The panels decided on research efforts to identify the pulmonary effects of inhaled gas mixtures and on the characterization of nonneoplastic respiratory disorders in the workforce. Such disorders may be the most prevalent disease manifestation in oil shale workers.

The terrestrial effects panel also identified information needs related to gaseous emissons. The panel considered that airborne aerosols, gases, and particles represent a substantial threat to animal systems in their actions individually, in concert, or synergistically when they are inhaled, ingested with water or plant and animal food, or are absorbed through surface tissues.

Transport and Transformation Phenomena

Common to most public health and environmental effects problems is the need to link air, water, and solid emissions released from a source such as an oil shale facility to the exposure levels of the pollutants or the products of their transformation in the ambient environment. This need, addressed primarily in the panels relating to air and water quality, is for sophisticated tools for tracing (modeling) the movements and chemical transformation of pollutants.

With regard to airborne pollutants, the air quality panel identified the need for a sophisticated transport and dispersion model capable of predicting air quality using source emissions and meteorological parameters. Research should begin on the refinement and application of a complex terrain model to the oil shale production areas and surrounding regions. Such a model must eventually address processes such as formation of secondary aerosols, deposition of gaseous and aerosol pollutants, resuspension of particles, and the contribution of natural sources in addition to the primary industrial emissions.

Water quality requires a determination of the fate of constituents released to the aquatic environment as a result of all aspects of oil shale technology. The fate of physical, inorganic, and organic constituents and the factors that mediate their routes and rates of movement and reservoirs need to be determined. Research topics of high priority center on organic constituents such as pyridines, anilines, quinolines, carboxylic acids, nitrogen-heterocyclics, and polycyclic aromatic hydrocarbons. High priority inorganic elements include arsenic, boron fluorine, and selenium.

Water Use

The potential effects of water withdrawals and discharges in oil shale areas pose a threat to the availability of quality water for human, agricultural, and industrial use, and to the vitality of terrestrial wildlife and aquatic organisms. Mine dewatering was considered by the terrestrial panel to be a high priority research topic because of its potential for severe impact upon the environment. The mining of oil shale will disrupt or dissect underground aquifers, requiring dewatering of the extraction zone for the protection of workers and the successful removal of shale oil or raw shale ore.

The water panel was primarily concerned with research related to the quantity, quality, and use of surface and groundwater. Major research areas relating to water resources include the availability and quality of water in streams, alluvial valleys, and bedrock aquifers; the impact of water withdrawal on groundwater levels, spring and stream flows, and aquifer characteristics; and the effects of subtle and long-lasting activities such as shale erosion and groundwater contamination that can produce effects that may take hundreds of years to become obvious.

Effects of Complex Mixtures

A central problem in the assessment of the health and environmental effects of oil shale activities is the limitation of time and resources to undertake physical, chemical, and biological tests on each of the numerous pollutants associated with each stage of the energy cycle. Such testing even if it could be undertaken and completed in time for industry commercialization may not be appropriate as receptors (natural fauna and flora, humans) are exposed to more than one pollutant at a time. Observed effects can be a result of pollutants acting in concert or in a synergistic (or perhaps antagonistic) manner.

The panel on ambient measurement and monitoring felt that it was impractical, at this time, to attempt to develop analytical methods for more than a small fraction of the total number of compounds generated in oil shale retorting and processing. Therefore, it recommended that class separation techniques be developed to provide families of chemicals which can be used in testing for toxicity and carcinogenicity. The panel also recommended that specific analytical techniques be developed for those compounds which are known or suspected to be particularly hazardous.

The health effects panel also recognized the need for a realistic assessment of the mix of pollutants from a variety of plants and processes. In situations where positive effects are observed, components of the mixture can be studied.

Baseline Information

Basic to the assessment of health and ecological effects is an awareness of the status of the environment in the absence of source emissions or disturbances. Constituents are expected to enter the envrionment from natural sources and from oil shale extraction, conversion, and utilization. Accurate, reproducible qualitative and quantitative measurements are necessary in order to establish existing environmental conditions, including the fate and transport of physical and chemical constituents, prior to any activity relating to oil shale development. In order to compare preoperational fate and transport with postoperational fate and transport, a preoperational database is required. Without the preoperational database, possible adverse environmental effects cannot be measured and related to oil shale development.

The terrestrial panel determined that a holistic overview of the undisturbed ecosystem is necessary to evaluate problems. The lack of such an overview has resulted in much of the confusion, inadequacies, and difficulties associated with environmental impact assessments.

Although it would be ideal to be able to make broad-scale comparisons of data obtained from other impact assessments, ecosystem baseline studies must focus on the specific region, site, or system being investigated.

Monitoring and Sampling Methods

Several areas of study on monitoring and measuring methods were identified as a high priority by the ambient measuring and monitoring, the water quality, quantity, and aquatic ecology, and the terrestrial effects panels. To ensure success of many projects, the information and methods used to measure and monitor oil shale-related energy activities must be valid and accurate. The basic findings are that it is essential for reliable analytical methods to be available for measuring potentially hazardous emissions in products, effluents, solid wastes, ambient air and water, vegetation, biota, and soil. This is especially important because the complex nature of oil shale-related materials causes serious interferences in many conventional analytical techniques.

Much of the anlytical work performed on oil shale and its related products has been limited to trace cations. Additional research is needed to develop similar multicomponent techniques for anions.

An area which should receive intense research effort in the near future is the development of rapid and continuous methods of analysis. This is particularly important for some of the airborne compounds such as potentially harmful polycyclic aromatic hydrocarbons, aromatic amines, nitrogen heterocyclic compounds, phenols, trace elements, and criteria pollutants. Real-time environmental analyses of these materials could permit correlation between plant operation, meteorology, and environmental and personnel exposure.

The archiving of samples is also important and will help meet several of the objectives of assessing the environmental influence of the oil shale industry. It is important that samples be collected and stored prior to the operation of pilot and demonstration plants so that pollutant concentrations in samples collected during or after the operations can be compared with those collected in baseline samples. With this information, it will be possible to determine the influence of plant operation on a wide spectrum of potential environmental pollutants.

Quality Assurance

The water panel determined that quality assurance and quality control on the collected water quantity and quality data must be adequate for the intended use of the data. Data that are not sufficiently accurate or precise may result in perturbations that are an artifact of the data collection system, in misinterpretations of the data, and in erroneous conclusions. Data needs relevant to this topic include information from data users on the required level of accuracy or precision and identification of the state-of-the-art of sampling techniques, analytical methods, and equipment needed.

The panel on ambient measuring and monitoring determined that to date, the analysis of oil shale and related materials has been plagued with serious analytical problems. The panel, therefore, recommended that serious attention be given to a quality control program that can assure the reliability of analytical results.

PANEL REPORTS

The panel reports presented in this section are a product of the participants in the workshop. The reports have been retained in their distinctive, original style as prepared by the panel chairmen. The report of each panel was reviewed by the panel participants and revised according to their comments.

Most panels found it difficult to rank problems in order of importance. The health effects panel met as a whole and voted on which of the problems presented by all subpanels should receive primary attention. The terrestrial effects panel developed a lengthy list of problem areas grouped according to their relative high, medium, or low priority. Other panels such as the air quality panel determined that dependence of problem definitions on a quantitative assessment of source emissions and their rates and speciation (largely lacking) prohibited a definitive ranking of problems according to their significance. Although the air quality panel identified seven problems associated with the oil shale technology, it felt that the ranking of problems other than of being of major or minor importance was not satisfactory. Within this framework, the panel assigned priority to those problems with human health implications.

HEALTH EFFECTS

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HEALTH EFFECTS

1.0 INTRODUCTION

Oil Shale has long been known as a possible source of energy. If the demand for liquid fuel grows and the desire for domestic self-sufficiency continues, oil shale should become an increasingly feasible source of potential energy. As with any fossil fuel technology, there are potential health problems associated with the extraction, conversion, and combustion of the oil shale resource. This conference has attempted to deal with those problems which are unique to oil shale with lesser emphasis on the generic fossil fuel problems.

The health effects panel was asked to analyze the shale oil fuel cycle and, in light of the current state of knowledge, to identify potential problem areas which should be studied to identify and assess health impacts which may be associated with use of this natural resource. This charge included identifying biological effects of pollutant exposure as well as potential safety hazards. Effects in these areas were considered for both the general and the occupational populations, but emphasis was placed on detection of possible occupational effects as they might serve as indicators of more subtle effects in the general population.

1.1 Approach

The panel first met as a whole, which provided the opportunity for panel members to describe their individual areas of expertise and their current research efforts. The entire panel then proceeded through the steps of the oil shale fuel cycle and identified, in a

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preliminary fashion, a number of potential problem areas. This period also served as an education session for those panel members who were previously unacquainted with this technology.

Based on the preliminary identification of problem areas and the backgrounds of the panelists, the full panel then broke into five subpanels to systematically review the problems and research required in each area. The subpanels which were chosen included:

- pulmonary effects,
- skin effects,
- developmental effects,
- epidemiology, and
- occupational safety and health.

Additional problem areas which included neurotoxicology, industrial hygiene and biological metabolism and fate were also identified by individual panel members and are included in this report. Once the problem areas within each subpanel had been identified, the groups then proceeded to identify the associated information requirements and related research projects.

During the subpanel working sessions, the entire panel reconvened on several occasions for special presentations from the source characterization panel on the identities of potential pollutants and from a USGS representative on the nature of potential water resource problems. At the conclusion of the subpanel sessions, the whole panel reconvened to discuss the problems identified by the subpanels and to assign relative research priorities.

The health effects panel identified a total of twenty-five problems and sixty-eight associated research tasks. Panelists were asked to ignore all time and funding constraints. The panelists at the conclusion of the conference felt that the major problem areas requiring attention if oil shale is to become a commercial energy technology were identified.

1.2 Summary of Panel Findings

As the meetings progressed, the following philosophy for guiding health effects research for oil shale became evident and can serve as a summary of the panel findings.

The panel felt it was essential to assess health effects of materials associated with energy technologies in terms of their hazard potential rather than their toxicity. This approach defines toxicity as the degree of detrimental effect introduced by a material that has gained entry into the body. This definition says nothing about the conditions of use of that material, it merely relates dose to effects. On the other hand, the hazard of a material can be defined as the potential for that material to produce a detrimental effect taking into account both the toxicity of the material and the potential for human exposure and intake. It is very clear that a number of toxic materials are associated with the oil shale industry which do not represent hazards. It is the panel's intent to avoid terminology confusion and to permit the industry to develop in such a way that only those toxic materials which are also hazards receive attention both from the health and the energy engineering communities.

Implicit in the approach recommended by the panel is a strong industrial hygiene and occupational medicine program to be carried out early in the development of the technology. This program, focused on the sites where pilot or commercial-scale operations are underway, has two purposes: first, it identifies the kind and degree of exposure that may potentially occur and second, it provides a source of actual material for use in biological assessments. Two concerns must be kept in mind which are directly related to the industrial hygiene sampling programs, neither of which can be reconciled definitively at the present time:

1. Extrapolation from Pilot Plants to Commercial-Scale Operations

It was argued that it is difficult if not impossible to extrapolate pollution from existing plants to that from the ultimate commercial-scale plant. This then poses a dilemma: how can the engineer prepare to control emissions/effluents based on their potential for health effects until the health scientist informs him of the need to do so and how does the health scientist recognize the need until he is aware of the potential for release?

2. How to Deal With Complex Mixtures of Pollutants

The need for a realistic assessment of the mix of pollutants from a variety of plants and processes complicates the situation still further. In addition, these pollutants can be degraded and metabolized into a still larger number of substances with unknown biological effects.

Since pilot plant operation is obviously the key to both technology and health assessment, the biologist and engineer must work closely together during this phase. Using the basic assumption, which must be validated in the commercial-scale plant, that the pollutants from the latter must be estimated directly from the pilot plant emissions and effluents, then identification and assessment of the biological effects of these pollutants should become an important program focus.

Three routes of exposure to effluents/emissions may be encountered in oil shale industry operations. The most likely is inhalation, followed by cutaneous, with ingestion* being even less likely. For both the inhalation and ingestion routes there are well-developed procedures available for determining exposure and evaluating the fate and effects of material entering the body. These procedures can be used in a way that readily links them to the potential for actual exposures. The consequences of the cutaneous route of exposure are more difficult to assess and link to actual exposures. For example, good techniques are not available for exposing the skin of animals to collected oil shale dust and quantifying the degree of retention.

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*Ingestion is likely to be a hazard only if mining results in contamination of regional aquifers.

Proceeding on to an actual assessment of the health effects of the various materials, it is apparent that there are a multitude of toxicological procedures available. The problem is to identify which procedures can be used most advantageously and appropriately to serve as input to a hazard assessment. The panel felt that it was essential to utilize approaches that took advantage of whatever human data might be available from either past, current, or future human exposures. Recognizing the paucity of human data, information from laboratory animals and simpler biological systems must then be extrapolated to humans.

Limited shale oil production has been underway for some time in the U.S. and abroad. Likewise, both oil shale and shale oil have been used as combustion fuels and as raw material for further processing. The persons associated with these activities should be studied to the maximum extent feasible in retrospective epidemiological studies. Individuals now working in the industry or who are employed in the future should be included in prospective studies where there is opportunity not only to document the health status of the individual on a continuing basis, but also to document their work and exposure conditions. Any findings, negative or positive, from these epidemiological studies should be used as major input to determining the nature of studies with laboratory animals or simpler systems. Conversely, the results from any laboratory investigation must be carefully considered in planning or redirecting the epidemiological observations.

Similarly, there must be a linkage between studies with whole animals and those with simpler systems such as tissue explants, cell suspension assays or use of microorganisms. Whole animals can be exposed such that the conditions of exposure mirror those of humans, thereby facilitating the extrapolation of the results of whole animal studies to humans. On the other hand, such studies are expensive and take a long time to conduct, especially if information on life-span, low-level exposures is to be obtained. Faced with the limitation of cost and time it is important that initial whole animal studies be conducted with materials identified from industrial hygiene studies as being those to which people will most likely be exposed. The results of these intensive studies can identify toxic effects that should be rigorously evaluated using more specific test procedures. Inevitably whole animal studies, at least in early stages of the assessment program, are likely to be conducted with complex mixtures. In situations where positive effects are observed, components of the mixture may be studied using simpler systems. Similarly, screening tests for mutagenicity (and presumptive carcinogenicity) and teratogenicity may be used to study more numerous samples, including both mixtures and individual compounds, to provide presumptive toxicity predictions for man and to suggest materials for more detailed evaluation in whole animals.

The panel recognized the importance of industrial safety, especially because of the developing nature of the industry and the associated use of new and novel work procedures such as those used for preparing the large underground rooms for modified in situ recovery of shale oil. It was the panel's opinion that the potential for worker injury and loss of life from industrial accidents might well have an impact equal to or exceeding that from exposure to various emissions or effluents. Further, it was recognized that injury or loss of life from accidents is usually immediately evident whereas effects from exposure to emissions or effluents may have a long latent period and may not be readily or uniquely relatable to the individual's immediate or past work experience. Thus, it is apparent that an aggressive industrial safety program should be an essential part of the oil shale industry operation.

Since the industry is still in its infancy, there is an opportunity to prospectively evaluate, and where necessary, modify work procedures to make them as safe as possible from the onset rather than having to respond after the fact to an unacceptable frequency of accidents.

Throughout its deliberations, the panel emphasized its concern for the use of an integrated approach to assessing health effects not only of the oil shale technology but of other alternative energy technologies as well. If the research is to have its fullest impact, it must be focused on assessing potential health effects in man and not become merely a collection of studies using materials that are encountered in the oil shale industry.

The problems identified above and in more detail in sections 2.0 and 3.0 of this report, though expansive in scope, may not address all of the issues which may surface as the oil shale technology is developed. Any research program addressing oil shale health problems must therefore remain flexible and aware of new technological developments.

2.0 GENERAL PROBLEM AREAS

In the course of trying to define the potential for health and safety effects associated with oil shale, the panel identified a number of problems which were common to more than one of the subpanels. These problems will be discussed in this section, with the problems identified by the individual subpanels being discussed in Section 3.0.

A number of the general problems identified by the health and safety panel are related to the identification and availability of materials for testing. Choosing the compounds for which testing will be required is complicated by the fact that these substances occur in complex streams. For preliminary testing for biological activity and perhaps mutagenicity screening, the panel felt that complex mixtures should be tested. Based on these preliminary results, the test sample could be provisionally eliminated as negative or be disaggregated further and the submixtures tested. This process can be repeated until the active pollutants or combinations have been identified. This approach was preferred by the panel to the approach which starts by screening individual pollutants and then combines them to see if there are synergistic or antagonistic effects. However, it is recognized that improved techniques for testing of complex mixtures must be developed, especially to overcome the problems of cytotoxic effects of one material possibly obscuring mutagenic responses of another.

In selecting materials for testing to determine their toxicity, it is important to consider whether the test sample should be taken before or after control technology is applied. The panel felt that samples should be taken both before and after the application of control technology to document its effectiveness. However, primary attention should be directed to characterizing the emissions streams as they are released to the environment after control technology has been applied, since these are the emissions of potential concern for the general population. Those samples taken before the application of control technology provide information on the potential for effect associated with the fugitive emissions to which the occupational population is exposed. To determine the nature of the hazard to the occupational population associated with fugitive emissions, in-plant monitoring and sampling must be undertaken.

The health effects panel expressed the need on several occasions to have available a repository of standard samples taken at various stages of the fuel cycle representing the various raw materials and technologies. A DOE representative stated that a joint program with DOE, EPA, and NBS was underway to establish a sample bank. Problems had been encountered in the preliminary stages, however, due to the chemical reactions and decomposition of the samples under normal storage conditions. The need to evaluate transport and storage procedures was made evident, and this area should receive immediate attention since only through use of common sample material can results of different biological tests be compared.

In order to develop comparative estimates of health effects of oil shale associated with its use and those from conventional energy sources, there is a need to designate a standard material for comparison purposes in various test systems. This might be a conventional petroleum product or a specific type of coal. There is also a need for a standard dust as a benchmark for evaluating respiratory effects. Associated with the selection and preservation of samples for testing is the problem of identifying the various components of the emissions and process streams for the oil shale technologies. The health effects panel repeatedly voiced a request for pollutant stream characterization in order to predict the nature and severity of possible health effects. This was needed not only for occupational health and safety studies but also to predict general population effects. As the various pollutant streams are characterized, these data should be made available to researchers so they can more accurately relate their studies to the actual situation.

This need for information dissemination both on technology aspects of oil shale and on related health and environmental research caused the panel to suggest the establishment of a central information center for oil shale. It would collect and make available both published and unpublished data and would serve a valuable current awareness function. This center might also be designed along the lines of the Air Pollution Technical Information Center to respond to specific information requests using a computerized file of available data with back-up shelved storage. No suggestions were made as to the lead role for this function or where it should be physically located.

There was, in general, an effort to avoid extensive consideration of the problems generic to all fossil fuel technologies. One area which should be mentioned, however, is the need for better mechanisms to relate subhuman testing data to the human occupational and general populations to predict effects. This is especially true for oil shale where only a very limited number of workers exist who have been associated with this industry. This means that epidemiological data are scarce, and most health-related decisions will have to be based on test results using subhuman species.

3.0 SPECIFIC PROBLEM STATEMENTS AND RELATED RESEARCH REQUIREMENTS

The interests and experience of the health effects panel seemed to naturally divide into two areas:

1) those researchers concerned with determining and measuring biological effects due to pollution exposure, and
2) those concerned with occupational health and safety.

Several subpanels were then selected within each of these areas. In the following text the problem areas identified by each subpanel are presented along with related information needs and the research required to address the problems.

3.1 Biological Effects

The biological effects associated with exposure to oil shale pollutants are a function both of the route of exposure and the pathway to the target area(s). Inhalation and skin exposure are obviously the most dominant routes with ingestion being much less significant except possibly for modified in situ operations which may result in aquifer contamination. Once the pollutant enters the body it may pass to other target organs causing metabolic, functional, neurotoxic, developmental or genetic effects. Subpanels were formed to identify problems associated with pulmonary effects, skin effects and developmental/genetic effects. Additional problems associated with neurotoxicology and biological metabolism and fate were also contributed by individual panel members.

3.1.1 Pulmonary Effects

During oil shale mining and the preparation of shale for retorting, much dust is created. Obviously those processes such as the Lurgi-Ruhrgas, the Superior or the Tosco II which require fine grinding of the raw shale before retorting will have the potential for release of fine dust particles in the range known to result in pulmonary retention. The Union, Paraho, Tosco II, Lurgi-Ruhrgas, Superior, and USBM processes will also generate large amounts of spent shale requiring disposal. The process of spreading the spent shale and its potential to release dust upon exposure to surface winds will result in occupational exposure to spent shale dust as well as potential down-wind exposure of the general population. Other problems associated with spent shale disposal such as bioconcentration through the food chain and leaching, which could affect humans, were considered in detail by other panels, e.g., terrestrial and aquatic effects.

In addition to exposure to dust during mining, crushing, and spent shale disposal, oil shale workers will be exposed to other airborne emissions from the various retorting and refinery processes and such secondary pollution sources as diesel exhaust from large machinery. The synergistic effects of smoking must also be taken into account in any analysis of pulmonary effects of shale pollutants.

The primary effect of concern is respiratory cancer, but fibrogenic disease as well as functional disorders must also be considered. The worker population receives the largest exposure and therefore becomes the major target to be monitored and protected.

Three major problems were identified by the pulmonary effects sub-panel.

3.1.1.1 Effects of Inhalation of Raw and Spent Shale Dust. The first problem addresses the inhalation hazard of raw and spent shale dusts alone and with such additional insults as diesel exhausts, NO_x and SO_x. The types of exposure will vary on a process-specific basis. For example, the room and pillar mining approach used by the Union, Paraho, Tosco II, and Lurgi-Ruhrgas processes will cause worker exposure to raw shale dust plus the diesel exhaust from the heavy equipment used for mining and hauling. On the other hand, in situ retorting processes will result in far less dust exposure.*

The disposal of spent shale will result in worker exposure to dust with very different composition and properties from the raw shale ore associated with mining. Depending upon both the shale resource and the retorting process, the spent scale can be expected to vary a great deal. The effects of these spent shale dusts on the respiratory system must also be determined.

Because of the differences in both the exposure patterns and the resulting dust composition, it will probably be necessary to determine the potential to cause pulmonary effects on a process-specific basis. A more complete assessment can be made when the results of the initial industrial hygiene sampling and characterization become available.

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*This refers to true in situ processing, not modified in situ processing which may result in significant dust inhalation associated with the relatively large-scale mining efforts.

Task 1 - In order to determine the dose-response effects of various types of shale dust associated with mining and spent shale disposal, life-span inhalation exposure tests are needed. To enhance the extrapolation of the results of such exposures to man, at least two laboratory animal species should be used. Dusts from different mining locations and those associated with spent shale resulting from various retorting processes should be tested in parallel to determine comparative effects. Appropriate fibrogenic and carcinogenic positive controls should be run. The exposure concentrations used for these life-span studies should be determined based on available industrial hygiene information.

Task 2 - Life-span inhalation exposure tests in two mammalian species are also needed to determine the combined effects of exposure to raw shale dust, diesel exhaust, and other important fumes or vapors present during mining. These additional substances might include SO_x and NO_x whose physiological effects are known to intensify in the presence of particulates. Again appropriate fibrogenic and carinogenic controls should be run and exposure concentrations should be derived from on site industrial hygiene observations.

Task 3 - Mechanistic studies using small groups of mammals are needed to define the nature of the pulmonary response and the role of macrophages and other cell populations to exposure to raw and spent shale dust alone and when combined with diesel or other relevant vapors. Groups of 25 to 30 animals could be used with three-to-five groups of animals being exposed to single and multiple doses. These mechanistic studies should involve some animals scheduled for serial sacrifice.

Task 4 - Limited studies should be conducted with groups of rodents intratracheally exposed to single or multiple doses of raw or spent shale dust. In addition, controls should be similarly exposed to quartz dust and known pulmonary carcinogens. There should be some serial sacrifice involved. There was agreement that intratracheal injection studies cannot substitute for inhalation studies. The advantage of intratrecheal injection is that one knows the exact amount of material deposited in the lungs. Inhalation lets one know the amount of dust going into the animal's nose and respiratory tract, but the amount of dust deposited in lungs is unknown.

Task 5 -Rodent species should be exposed in a parallel multi-concentration dose experiment to dusts from Estonian and U.S. Green River Shales. In addition, full characterization of both test materials is required to attempt to explain any differences in effects between the two treated groups. A quartz aerosol control should also be run.

Task 6 - Much of the western oil shale is embedded in nahcolite, a mineral high in sodium. Inhalation of nahcolite dust from oil shale mining or spent shale disposal could present a health hazard to those workers or members of the general population required to maintain low salt intake. The effect of nahcolite inhalation on blood pressure should be measured using appropriate animal models.

3.1.1.2 Effects of Inhalation of Routine Oil Shale Gaseous Emissions. Extraction of shale oil (kerogen) from the raw shale resource involves worker exposure to routine emissions from both retorting and plant maintenance. Operation of both in situ and surface retorts will result in the inhalation of a mixture of aerosols and gases. The aerosols will contain raw shale oil components and other volatilized organic chemicals, especially polycyclic organics, and raw and spent shale dust particles. The gaseous exposure will include organic vapor with some exposure to oxides of nitrogen, sulfur, and carbon. The chemical nature and particle-size distribution determine the nature of the inhalation hazard, but they will vary with the retorting process and the operational parameters. Fugitive emissions will be process and job-specific.

Task 1 - The carcinogenic and co-carcinogenic potentials of inhaled mixtures containing major classes of routine and fugitive emissions singly and in combination with each other should be evaluated in two species of laboratory animals. The complex mixtures to be tested should be process specific. For the aboveground retorting processes, the test exposure should initially emphasize both raw and spent shale dust in combination with crude shale oil. Because direct and indirect heating are expected to give rise to chemical differences in the crude oil and spent shale, studies for aboveground processes should include materials from both types of processes.

Modified in situ processes should be similarly evaluated. Care should be taken during exposure to provide appropriate particle size and particle chemistry. Prior to these animal studies, detailed physical/chemical characterization of the test materials is required. Guidance as to the specific materials to be used in the exposures should be obtained from the initial industrial hygiene sampling and characterization studies.

Task 2 - For those mixtures which showed carcinogenic or co-carcinogenic potential in the above task, the biological activities of specific key components should be determined. The mixtures must be process specific but the active components may, in fact, be common to many processes.

Task 3 - Development of non-neoplastic respiratory disorders in the occupational workforce may be the most prevalent disease manifestation in oil shale workers. Inhalation studies of two to three year duration in long-lived species are required in disease-free animal models to evaluate morbidity. Detailed pathological evaluations and pulmonary function measurements should address the potential health hazard of carefully selected combinations of shale-related emissions. In this regard, exposure to quartz and shale dust alone and in combination with other effluents should be specifically evaluated.

Task 4 - Early and sensitive indicators of the biological consequences of exposure to oil shale products are required to develop realistic protection of occupational health. Detailed evaluation of the early effects associated with respiratory tract disease development is required. The specific studies to be undertaken to evaluate early changes can best be defined after the results of the initial life-span studies are in hand. With knowledge of which specific diseases are influencing mortality, specific early indicators of these diseases can be sought. These studies may include examination of immune status, lung clearance capabilities, and exfoliative cytology.

3.1.1.3 Inhalation of Refining Products Originating from Shale Oil. While many of the chemical species resulting from processing of shale oil are the same as those resulting from processing of petroleum, some significant differences have been identified. Cyclic hydrocarbons, structurally similar to known carcinogens and co-carcinogens, are present which are common to other fossil fuel technologies. While it may be possible technologically to control their formation and/or release, a health assessment is warranted, both of the processing and the ultimate fate of the combustion and end-use products. Comparisons of the health assessments of end-use products under varying conditions of use and misuse (malfunctioning engine systems) should employ existing fuels as a standard reference point.

Task 1 - There is a need to quantify the exposure of the occupational population to by-products associated with shale oil refining to which they may be exposed. Prior to determining the exposure, the waste streams must be characterized including identification of individual inorganics and polycyclic organic matter. Research suggests that these organics and inorganics are probably very similar to those found associated with normal particulate matter in air.

Task 2 - Multiple-dose level, long-term studies of the inhalation effects of representative, refined, shale oil products such as LPG, gasoline, stove oil, jet fuels, heating oil, and diesel fuel should be conducted in appropriate animal species. These studies should include determinations of the metabolic fate, disposition, and toxicological manifestations associated with the pollutant inhalation. Dose-response relationships for the various vapors and emissions resulting from other synfuel production processes should be included in the study to provide a point of comparison. Emphasis should be placed on studying those products which have significant chemical differences relative to conventional petroleum products.

Task 3 - The toxicology of inhalation of emissions and combustion products resulting from use of products obtained from shale oil remains to be determined. Some work in this area is being supported by the Navy, but it may need to be supplemented by additional work if shale oil-derived fuels become available on the commercial market. Long-term animal studies using several dose levels in appropriate animal species should be carried out using emissions from various types of products listed in Task 2. Guidance as to which fuels should be studied can be derived in part from the results of comparable studies carried out with conventional petroleum products.

3.1.2 Skin Effects

The skin serves as an interface between man and his physical, chemical and biological environments. It is an important portal of entry of hazardous agents and is a vulnerable target tissue for damage by chemical and biological agents. A large number of occupational skin diseases resulting from chemical exposure have been documented. Potential skin problems include: non-allergic inflammatory responses, i.e., irritation and/or corrosive action; allergic or hypersensitivity reactions such as immediate hypersensitivity and cell-mediated response (contact dermatitis); photosensitivity including phototoxic and photoallergic reactions; pilosebaceous reactions such as aceform reactions and damage to hair or hair follicles; sweat gland reactions such as miliaria; pigment reactions, and cancer.

From state worker's compensation records, it appears that skin-related illness comprises 35 to 85 percent of all occupational disease. Hence, it is important to estimate and evaluate the effect of various oil shale emissions and fractions on the integumentary system. These fractions should include the dust associated with raw and spent shale, the various gaseous vapors and emissions, and the liquid products.

It is essential to understand the physiological and biochemical aspects of percutaneous adsorption, the factors which enhance cutaneous penetration, and the agents which are known to induce changes.

At the present time, methods to evaluate toxicity from inhalation and ingestion studies are well known. Much less is known about documenting dose-effect relationships if a substance comes in contact with the skin. There is need for an evaluation of the skin-painting methodology to document its ability to predict toxic effects due to normal or accidental occupational exposure.

3.1.2.1 Effects Associated with Skin Absorption and Penetration by Substances Associated with the Oil Shale Industry. There is a need to describe and quantify the effects of skin exposure. The whole absorption and penetration process needs to be studied and those agents which facilitate and suppress absorption need to be identified. In choosing the substances or mixtures to be tested on skin, guidance from the industrial hygienists is needed as to the fractions from the various processes to which the workforce is most likely to be exposed. Previously some work has been done to study skin hazards due to foreign (Estonian) oil shale products. This information will be a great asset to evaluation of toxic and localized effects of oil shale products on skin. At the present time, a controversy exists over whether benzene and other light solvents likely to be present in shale oil are absorbed by the skin. Research in this area would help to solve this controversy.

Task 1 - A literature survey is needed to determine the current state of knowledge regarding techniques used to measure the rate of absorption and penetration through the skin of organic and inorganic compounds, especially those associated with fossil fuels. It is essential to collect all related data available for foreign oil shale materials and compare them with data on domestic oil shale materials regarding their physical, chemical and biological properties and mode of action on skin. These data would be valuable for comparison of the foreign and domestic oil shale resources and their relative abilities to cause dermal effects.

Task 2 - Indices of the rate of skin absorption and penetration should be developed for dermal entry and measurement of effects attributable to raw shale dust and shale oil fractions from all major processes. These indices must be related to such variables as skin thickness and pore diameter. From these data it may be possible to derive a set of standards for exposure for various types of skin depending, for example, on age or sex.

Task 3 - It is necessary to develop a test system to identify and measure the rate of penetration of isolated compounds or shale oil fractions with/without other surfactants, humidity, UV-A, UV-B, temperature or other environmental agents. This interaction between oil shale toxicants and other surfactants is important as it provides information on their possible synergistic function.

Task 4 - It is essential to measure rates and quantity of penetration of oil shale products at different temperatures and humidity conditions in animal epidermal tissue. Comparative rates of penetration for different process streams from various oil shale technologies need to be identified.

Task 5 - Skin painting of various oil shale fractions should be done in an *in vivo* test system to determine carcinogenic potential as a function of localized absorption. It has been previously reported that polycyclic aromatic hydrocarbons such as methylcholanthrene (MCA) and phorbal esters such as TPA have resulted in the formation of cutaneous tumors in mice. This technique can also be used to measure co-carcinogenesis and carcinogenic promotion in the presence of other potential carcinogenic chemicals.

3.1.2.2 Control Measures Required to Minimize Effects Due to Dermal Exposure. Once the effects associated with exposure of the skin to oil shale-related pollutants are known, means should be developed which can minimize or eliminate these effects.

Task 1 - The emissions and effluents from the oil shale fuel cycle have many common ingredients with those from other fossil fuel cycles. Some work is being done to learn the effects of other fossil fuel pollutants which will increase the knowledge of the potential effects of oil shale products. Mitigating hygienic measures useful against these other fossil fuel pollutants should be evaluated for use with oil shale.

Task 2 - Monitoring procedures are needed to assess the degree of dermal exposure to oil shale-related pollutants. Once this assessment is done, appropriate engineering techniques can be applied to ensure effective containment.

Task 3 - Pre-employment and periodic screening for various dermal disorders is another way of reducing exposure of workers. Educational strategies for hazard control should be identified and workers should be trained so they will make a conscientious effort to reduce exposure to oil shale toxicants.

3.1.2.3 - Effects of Underground Climate during Mining Operations on Skin Effects. The underground climate, namely mine temperature, humidity, and pressure may affect dermal exposure. The level of human pathogens or microorganisms in mines should be investigated and a determination made whether they can alter the susceptibility of workers to infection through the skin in the presence or absence of other physical or anatomical factors such as the oil content of the skin. Decontamination of potential pathogens and harmful microbes is necessary to minimize the risk. Studies performed by Colony with old processed shale, showed only normal soil bacteria, so it remains to be seen whether this is in fact a problem.

Task 1 - Identification is needed of microorganisms and potential pathogens at various mine depths. Sampling of mines using swabs and aerosol monitoring should be performed to determine the extent of microorganism contamination. If significant contamination is found, various control methods such as the use of fungicides and bacteriocides need to be investigated to determine those most effective against shale mine microorganisms. In addition, the effect of physical agents such as temperature, humidity, and pressure in mines on the rate of absorption and length of retention of various identified oil shale pollutants in the presence of microbes on skin should be evaluated. All variables need to be considered for vulnerability of humans in mines.

3.1.2.4 Interaction of Shale Oil Components with Other Chemicals. There is a need to assess the interaction of chemicals from oil shale on or in the body with other chemicals such as drugs, food additives, ambient pollutants, alcohol, and tobacco. These chemicals may have different routes of entry other than skin, but there is a possibility that they may have secondary effects in causing potential skin reactions.

Task 1 - *In vitro* submammalian tests and mammalian tissue culture tests may serve as indicators of toxicity of oil shale materials to epidermal tissue in the presence of drugs, food additives, alcohol, and tobacco. This dermal tissue toxicity may be due to additive or synergistic interactions. The data thus obtained will be useful for later *in vitro* studies for carcinogenesis using skin cells.

Task 2 - The results from Task 1 will provide information of dose-response to oil shale materials. These lethal and sublethal concentrations can be used in *in vivo* animal tests to determine their potential to cause benign or malignant lesions. To study the developmental aspects of cancer, animals need to be sacrificed periodically during the studies, if death is not the end point and one is interested in pathological characterization.

3.1.2.5 Utilization of Skin as an Assessment Model. If it is found that toxic chemicals are assimilated by occupational personnel through their skin, there may be need for development of a model test system to measure effects of specific process mixtures. Skin, an easily available human tissue, can be obtained by skin punching similar to that being used in skin biopsy for cancer detection. The punches in tissue culture can also be used to assess effects of primary irritation and allergic sensitization as well as histological changes.

Task 1 - Development of a model skin system should begin by obtaining skin punches from voluntary oil shale workers exposed to various materials in process streams and by-products. These results can be easily compared with volunteers from the general population that are matched for age, sex, habitat, etc. Estimated exposures to the various oil shale pollutants should also be obtained for the workers who are tested. The data obtained will serve to develop a questionnaire for epidemiological industry-related studies.

Task 2 - Once such a model (ie., the skin tissue-culture model) is developed, it can be used as a realistic protocol for testing raw and spent shale dust, shale oil, and shale oil fractions for carcinogencity, mutagencity, and toxicological manifestations. This test model can be employed as a screening method and as a quantitative measure to develop exposure standards. Co-carcinogenesis and initiating and promoting potential of complex mixtures of oil shale by itself or in the presense of extrinsic environmental factors can also be analyzed using such a model.

3.1.3 Genetic and Developmental Biology Effects

It is not now known whether emissions from oil shale activities present high risk problems for man in this generation or in the future. It is obvious that we must minimize the possibility of oil shale operations contributing to the genetic load. Therefore, the objective is to prevent human exposure to various shale oil components or fugitive emissions which are shown to be potential mutagens or teratogens during all phases of the oil shale fuel cycle. Which individual components or combinations thereof are of greatest concern are, at the present time, only speculative.

The potential for adverse effects on genetics, libido, fertility, and on the conceptus seems real and therefore, raises the need for an intensive and process-oriented testing program before large-scale production of shale oil occurs. This can be accomplished by testing process mixtures and individual fractions for effects on reproductive processes and for possible mutagenicity and teratogenicity. This will provide added assurances that the new technology does not represent a hazard to man in future generations.

3.1.3.1 Identify the Potential Mutagenic Hazard of Oil Shale Process Materials. Because of the anticipated growth and development of the oil shale industry, the by-products of the various processes and fuel cycles need to be evaluated for their ability to cause mutagenic effects. The sensitivity of cellular components of the body to gaseous, liquid and solid oil shale effluents and by-products is unknown and studies need to be initiated to identify the suspected mutagens and teratogens. This valuable information will help to evaluate potential human risk.

Most of the mutagenic compounds identified so far in mammalian germ cells and various sub-mammalian *in vitro* systems are alkylating agents. Baseline data on their mutagenic potential are especially needed for polycyclic organic matter and trace metals which are likely to be associated with oil shale processes. However, some of the compounds which are strong *in vivo* mutagens such as procarbazine give only weak responses to an Ames plate test and vice versa (e.g., aspirin). The reasons for these different *in vitro* and *in vivo* responses need to be ascertained.

It was recognized that there are literally thousands of individual compounds present in the process streams, emissions and effluents of various oil shale processes. Not all of these can be given the same degree of attention. Therefore, it is clear that priorities must be established for determining which materials or combinations are to be tested and the tests to be used. An important input in establishing the priorities should be the results of industrial hygiene sampling and characterization which will not lower the number of chemicals but which can indicate the potential for exposures to various materials. Also, those compounds found to be common to a number of fossil fuel technologies should be given priority.

Task 1 - The recent development of short-term tests for mutagenicity provides a battery of techniques that can be used with large numbers of chemicals to provide rapid, inexpensive and comprehensive screening. These short-term tests using submammalian and *in vitro* test systems can serve as a guide for establishing priorities for further testing of specific chemicals in higher organisms and to aid in evaluating their mutagenic hazard under various exposure conditions.

The mutagenicity data provided from submitting various oil shale fractions, especially the polycyclic organics and trace inorganics, to the following battery of test systems will help identify the mutagenic fractions/agents:

1. *Salmonella typhimurium* (Ames) -- reversion assay
2. *Escherichia coli* -- forward mutation, reverse mutation, deletion
3. Yeast -- mitotic recombination and gene conversion
4. Chinese Hamster Ovary -- hypoxanthine-guanine-phosphoribosyl, transferase (HGRPT)
5. Human leukocytes -- cytogenetic damage
6. Human leukocytes -- sister chromatid exchange
7. Biphenyloxidase system
8. *Drosophila* -- sex-linked recessive lethals
9. Unscheduled DNA synthesis test

There is also a need to validate the ranges of effectiveness of these tests as predictors of human mutagenic response and to determine the weak and strong points of each test system.

Task 2 -Based on the results obtained from the *in vitro* and sub-mammalian screening tests, those fractions or substances which showed positive results should be submitted to a battery of *in vivo* tests to determine the exact nature of the genetic effects, the transport of chemicals to the germ cells, and their germ cell toxicity. The following tests should be considered for inclusion in the battery:

1. Seven specific locus test
2. *In vivo* somatic cell test (spot test)
3. Dominant lethal test
4. Heritable translocation test
5. Total reproductive capacity test
6. Specific locus mutation test (can test results of chronic exposure).

These tests can be run with mice or rats using inhalation as the primary route of exposure. Development of an overall testing protocol for oil shale, if properly designed, would be valuable since some of the above protocols can be combined with the result of decreasing both the time required and the cost.

3.1.3.2 Effects of Oil Shale Pollutants on Male Reproductive Capability. Workers will be exposed to fugitive emissions during raw shale extraction, retort operation, spent shale disposal and the distribution, refining, and use of shale-derived fuels. The amount of exposure will be dependent on the nature of the process and the worker's job. The influences of hydrocarbons, heterocyclics, phenols, nitrogens, carbon or sulfur oxides, and trace metals upon male reproductive capability is currently poorly defined.

Task 1 - An effort should be made to identify, collect, and review literature available on the reproductive effects of oil shale ingredients. This will avoid duplication in testing and will identify gaps in knowledge.

Task 2 - Methodologies exist to test effects of various classes of substances on male animal fertility and libido. These protocols are used to test drugs and were recently used to verify the observed effects in workers exposed to DBCP. These methods should be used for those oil shale fractions which are biologically active to see if they affect male reproductive capability.

3.1.3.3 Effect of Oil Shale Pollutants on Female Reproductive Capability and Teratogenic Effects. Females of child-bearing age may be exposed to fugitive emissions from shale retort operations, or during storage, transportation, and use of shale oil. Experience with other fossil fuel conversion technologies suggests that process streams and fugitive emissions at work sites or major accidental spills may release materials into the environment which pose some health risks to females of child-bearing age and to their offspring.

It is necessary to determine the reproductive and developmental toxicity potential of complex mixtures and selected compounds associated with oil shale technology processes.

Prenatal exposure to toxic substances may also result in functional disturbances to the developing nervous system which are manifested after birth. These behavioral teratogenic effects should be studied in animals that are exposed *in utero* to various mixtures of oil shale products by maternal inhalation, ingestion and dermal exposure. Toxicity related to behavioral teratology may arise from the occurrence of mutagenic processes which are expressed through behavior. Hence, multi-generational studies that include behavioral measures are obvious choices for toxicity assessment of oil shale products.

The developing conceptus often shows an enhanced sensitivity to toxic agents compared to the adult. Therefore, the effects produced by exposure to a variety of toxic agents during the prenatal period may become the limiting factor in establishing permissible exposure limits.

This information gained from rodent and sub-primate tests will be of value in subsequent stages of technology assessment by identifying areas or materials that require more attention to prevent human exposures to potentially harmful materials. Those classes of materials expected to pose the greatest risk are trace elements, phenols, and polycyclic hydrocarbons.

Task 1 - A literature survey of studies on humans and animals should be conducted to determine the state of knowledge concerning the potential for reproductive and teratogenic effects associated with shale oil and fossil fuel-related materials.

Task 2 - Preliminary studies are required in laboratory animals to determine which components of the oil shale-related mixtures being tested would reach the reproductive organs and cross the placental barrier to the fetus. Alterations in the materials during biological transport should also be determined.

Task 3 - Acute and subchronic animal toxicity studies including oral, dermal, inhalation, and intratracheal exposure should be conducted to determine maximal tolerated doses in pregnant females and possible effects on their progeny. Effects on the progeny should be sought both before and after birth to detect structural or functional abberations.

The neonates from Task 3 can be further studied to test the inheritable traits in future generations by the method of backcrossing. The data thus obtained can prove or disprove heritable genetic damage due to exposure to various oil shale materials. To do this effectively will require the analysis of large numbers of offspring of treated parents.

Task 4 - Animal tests should be designed to test for neurological or behavioral changes in pregnant females and their neonates following exposure to oil shale materials. Neurological function changes can be seen as neuropathy, CNS impairment, or performance impairment.

3.1.4 Behavioral and Neurotoxicological Effects

Human behavior is a complex phenomenon with many determinants. Although behavior can clearly be affected by toxic chemicals, many other factors can also produce important changes. The behavioral consequences of exposure to heavy metals, pesticides, organic solvents, and noxious gases such as carbon monoxide are most frequently cited as illustrations of behavioral and neurological toxicity. The recent episode with kepone, an insecticide whose principal early toxic manifestations are behavioral, points out the importance of behavioral toxicity evaluation. It has been suggested that subtle psychologic effects may be attributable to such environmental toxicants as organo-phosphate pesticides. Hence, it is important to determine the neurotoxic effects of oil shale and oil shale products while the technology is still in the developmental stage.

At the present time, it is not known which of the biologically active oil shale pollutants may also exert neurotoxic effects. There is an indication that some fossil fuel components are neurotoxic. Those compounds are associated with the oil shale technology and petroleum products which should receive special attention are the polycyclic aromatic hydrocarbons, the less complex hydrocarbons such as xylene, toluene and phenols, carbon monoxide, and trace metals such as As and Hg.

3.1.4.1 Behavioral and Neurotoxicity Tests to Measure Effects Induced by Oil Shale Products. Concepts and methodologies to investigate subtle neurologic and behavioral expressions of toxicity attributable to environmental agents are currently only beginning to be developed. Analyses of the neurotoxicological effects of various energy-associated pollutants are not available, hence, it is necessary to study the neurotoxicity of oil shale products, emissions and effluents using animal test models. The results obtained need to be compared to results for other presently used fossil fuels, and these can be cautiously extrapolated to predict human response. The research should concentrate on the areas of neuropathy, central nervous system impairment, performance impairment, and behavioral changes.

Most of the research in behavioral toxicology has been directed toward the study of effects of known central nervous system toxicants in animals under laboratory conditions. The data available from animal models for inhalation, ingestion, and skin exposure studies are useful for predicting neurotoxicity of similar classes of chemicals released or formed during shale oil production. The state of current knowledge of any oil shale pollutant or related substance should, therefore, be ascertained prior to initiation of an elaborate animal testing program.

It is necessary to identify biochemical indicators in blood or urine which can be correlated with nervous system impairment.

Simple, sensitive and cost-effective tests for assessing neurotoxicity and behavioral toxicology will be useful. It is important to test and identify additive and synergistic effects of various oil shale process products and other confounding factors. These animal test results can be extrapolated to permit better risk assessment for workers in oil shale operations.

Task 1 - A survey of current literature of test methods and medical findings concerning neurotoxic effects of oil shale products, by-products emissions and effluents should be performed.

Task 2 - Animal models should be developed and standard test methods selected to evaluate such motor and sensory functions as vision, hearing, and memory. The methods developed for the assessment of sensory function in animals are time-consuming and costly, but their precision and sensitivity make them invaluable for the early detection of toxic effects. Similarly, animal tests for motor function can be developed and standardized.

Task 3 - Animal tests capable of detecting even minor changes in performances over long periods of time need to be developed. Such long-term testing is essential in the assessment of chronic exposure to low levels of effluents. These tests should be used to study whether premature aging of the nervous system occurs following exposure to oil shale-related substances.

Task 4 - Within the body, metabolites of oil shale effluents may interact with drugs, alcohol or tobacco smoke. These agents are known to affect sensory and motor functions and cause behavioral impairment. The interactive effects could be antagonistic or synergistic. This should be studied using multiple exposure models in animals.

3.1.5 Biological Metabolism and Fate

Since most of the unique biological effects associated with oil shale use are expected to be related to polycyclic organics, less complex hydrocarbons, and trace metals, there is a need to know what happens to these substances once they enter the body. Both *in vitro* and *in vivo* methods should be applied to study both pure substances and process mixtures since synergystic and antagonistic affects are known to strongly affect metabolic rates and pathways.

The physical/chemical properties of pollutants are important in determining their transport and general metabolism within the body. Their rate of dissolution, lipid solubility, charge, and polarity all determine the amounts of pollutants absorbed through the various entry organs.

Without question, thousands of man-years could be expended improving our knowledge of the fate of the myriad of materials encountered in oil shale operations. Even more time could be expended searching for the alternative metabolic products. It would seem appropriate to establish priorities for such investigations based primarily on (a) the results of industrial hygiene studies (b) the results of biological effects studies as indicators of materials capable of producing effects.

3.1.5.1 Conduct Studies of Metabolic Pathways and Fates of Pollutants Associated with Oil Shale. Animal models for human exposure to pollutants should be designed to provide insight into the fate of the material within the body. The approaches used should identify not only the fate of the material as taken in but also various metabolic products.

Task 1 - One must carefully select those processes/chemicals/ mixtures to be tested. When comparing various pollutants of the oil shale industry processes, it is important to know the physical and chemical properties of these pollutants to predict absorption, reactions, deposition, etc. This information can be obtained through a literature survey of those compounds identified in oil shale pollutant streams and structurally related substances. The data thus obtained from a state-of-the-art survey need to be updated as the technology advances.

Task 2 - *In vivo* animal studies can be conducted using radioactively labelled doses of a given pollutant administered to test animals to determine reaction rates, intermediates, and target organs. Brief exposures of animals to pollutants may be sufficient to measure metabolic pathways and transport rates; however, longer term studies should also be run to measure excretion and to identify intermediate-term deposition sites which may differ from short-term sites. Analysis of the labelled tissues can be done by scintillation counting or autoradiography. The use of labelled compounds also facilitates the identification of metabolic intermediates and ultimate metabolites. *In vivo* studies should provide valuable information regarding the metabolism of pollutants from the oil shale industry.

Based on the results of whole animal studies appropriate, experiments can be designed to use cells and tissues *in vitro* for more detailed evaluation of the fate of materials and especially enzymatic transformations. Such studies may also provide information on cytotoxic effects at the cellular level related to effects observed in the whole animal.

3.2 Occupational Safety and Health

Oil shale technology and knowledge concerning potential associated health effects are both in their infancy. This offers an opportunity for systematic planning and scheduling of research and development in parallel with commercial plant construction in response to needs for protection of human health. The availability of current pilot plants and overseas operations also offers the opportunity for the collection of data on emissions and health effects. Activities of two sub-panels were focused in these areas.

One subpanel examined the available epidemiological data and suggested three basic epidemiological activities which, when combined with exposure data, will enable significant cause-effect relationships to be established. These activities include:

1) Occupational surveillance of all oil shale plants
2) Community epidemiology studies

3) Industrial hygiene practices

4) Integration of 1) to 3) with emissions data

The second subpanel was concerned with the occupational safety procedures required by the new oil shale technology. It was noted that the physical designs of the mines may represent both physical and toxic hazards. This subpanel felt that a more thorough evaluation and development of remedial measures should be undertaken. They also recommended the creation of industrial hygiene programs to develop more sensitive and time-reactive monitors to detect and measure the toxic materials inherent in the refining of shale oil.

3.2.1 Epidemiology Studies

As with any comparatively new industry there is not sufficient evidence available to permit adequate judgments of the human health effects of the oil shale products and by-products. Some morbidity and mortality data based on domestic pilot plant experience as well as those from the Scottish and Estonian processes are available. Extensive literature searches combined with available data on industrial hygiene and environmental monitoring are indicated. The subpanel recommends expansion of these existing retrospecture studies to assure that maximum information has been extracted from past histories that are available for analysis. The subject populations should be evaluated for chronic diseases of a covert, long incubation period, e.g., malignancies, neurological dyscrasias, and pulmonary or dermatological effects.

Inherent in the consideration for expansion of the oil shale industry is the design of a valid prospective epidemiological surveillance program. The program should begin with thorough pre-employment physicals to collect baseline data and continue with structured periodic health examinations to assure that significant databases are constructed. These comprehensive clinical examinations should be selectively targeted to identify potential diseases which may result from exposure to specific etiologic agents associated with oil shale processes.

Additional data on long-term community exposure should be integrated in the database design and valid disease registries and reporting systems established. Flexibility in the design is required to incorporate new information as it is generated and analyzed. This is a unique opportunity to collect baseline data and to design prospective epidemiological studies. Similar studies to identify physical hazards unique to oil shale industries should be considered.

3.2.1.1 Conduct Retrospective Studies on Previously Exposed Populations. Populations both previously or presently employed in the oil shale industry should be intensely studied and followed for morbidity, mortality, and/or specific development of pulmonary, skin, neurological diseases, and cancer.

Task 1 - Populations exposed to oil shale pollutants should be identified. All information available should be collected and evaluated so that the value of further, expanded studies can be assessed.

New studies should be initiated as indicated by these preliminary findings. They should contain a common protocol that can be used for consistent comparison of data obtained from various oil shale industries. These populations should include:

a. Anvil Point 1952-66 (350 out of approximately 1200 workers are currently being followed)

b. Estonia

c. LERC

d. Sweden

e. Scotland 1922-48

f. Australia

Populations exposed to oil shale pollutants should be identified. All available information on them should be collected and evaluated so that the value of further expanded study may be assessed. New studies should be initiated as indicated by these preliminary findings.

Task 2 - The uses of existing morbidity and mortality data should be greatly expanded. Agencies such as the Bureau of Labor Statistics, Department of Labor, and the National Center for Health Statistics that have existing data on morbidity and mortality should be contacted. All available information should be pooled and used to facilitate epidemiological research of occupational diseases as a result of exposure to oil shale pollutants. These data can be of great value to determining the extent of morbidity and mortality attributable to the work environment.

Task 3 - Both cross-sectional and prevalence approaches are important in evaluating possible occupational disease. The advantages of the cross-sectional approach are that it requires less time and money. On the other hand, unless lifetime doses can be readily estimated, negative information can be misleading. Unless those workers who have left the industry are located and data on them are included in the analyses, the impacts of the occupational environment cannot be quantified.

Prevalence studies are important for projecting the effects of exposure to oil shale industry pollutants due to past occupational exposure. Prevalence studies should provide quantitative data on the incidence of possible occupational diseases.

3.2.1.2 Prospective Epidemiology Studies. In order to maintain continuing surveillance to identify health changes and detect deleterious effects in workers in the oil shale industry, prospective epidemiological studies should be initiated. Prospective studies are expensive and time-consuming, but can trace long-term latent effects.

Task 1 - A prospective study to cover all oil shale projects/ workers as they start up should be established. Data should be collected on each prospective employee in terms of previous medical and occupational history at the time of entry into the oil shale industry. For those workers already employed, complete data should be obtained, though true baseline data may be missing. A standard questionnaire will bring uniformity and comparability to the information received from employees at the time of employment and should be used by all oil shale facilities to permit pooling and later comparison of data.

Task 2 - Each employer should collect the data specified in Task 1 and update it periodically at the time of the workers' regular medical examinations. Medical examinations on a routine basis will offer valuable data documenting the trend in development of occupationally related illness.* Specific medical procedures such as pulmonary function tests, x-rays,EKG, dermatology studies, neurological exams, cytology and other disease related detection methods should be used. The employees should be asked to supply their data to a central file where they can be pooled and evaluated by a team of physicians, epidemiologists and statisticians.

Task 3 - Along with Tasks 1 and 2, it is necessary to collect data on the occupational history of all employees. To determine the effect of exposure to oil shale pollutants while on the job, it is necessary to know the identities and concentrations of the various pollutants to which the employees are exposed. Hence, detailed descriptions of previous and present employment should be collected using a standardized protocol.

Task 4 - A follow-up procedure after termination of employment should also be initiated and pursued at appropriate and periodic intervals. To do this, it will be necessary to maintain contact with the oil shale industry's former employees. These former oil shale workers should be made aware of the scope of the epidemiological study in which they are involved and the need for their continued cooperation.

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*These examinations should preferably be performed by practitioners not employed by the facility since their observations are likely to be more objective.

Compliance with and integration into the study should be stressed on the part of employer and employee. Medical examinations must be provided in a manner which fully protects the total health and continued employment of the miners. Flexibility to use vertical studies investigation must be maintained.

3.2.1.3 Community Surveillance. Surveillance and monitoring of communities which may be impacted adversely by the oil shale industry must be maintained. The incidences of disease in these communities should be monitored and significant differences should trigger specific in-depth investigation.

Task 1 - Existing registries of prevalence of cancer, heart disease, birth defects, etc. should be consulted to determine whether disease trends can be detected for the oil shale areas covering the states of Colorado, Wyoming, Utah and New Mexico. The database for these communities should contain, at a minimum, births, deaths, year, cause, and age. Continuing assessment of vital statistics for the oil shale industry and control area should be provided.

Task 2 - A review of the adequacy of existing registries should be conducted. The registries should be expanded if necessary in order to assure adequacy of database coverage and comparability with other related registries.

Similarly, if local and state funding become inadequate to maintain the registries, Federal assistance should be considered since they serve a valuable alert function.

3.2.1.4 Integrated Epidemiological Assessment of Risk to Man in and Around Oil Shale Facilities. It is important to combine data on emission of pollutants from the oil shale industry with various vectors of transport to estimate population exposure and health impacts.

Task 1 - Emission estimates for pollutants from oil shale operations and their transport via water, food, wind, and rain should be compiled to facilitate study of the estimated health impacts of oil shale operation on workers and the community. This should be done using a grid system to model emission measurements and resultant exposures. In selecting the oil shale operations for study, a variety of processes should be selected. The availability of epidemiological data through state registries should also be considered in choosing among several locations.

Task 2 - The monitoring data, from Task 1 as indicators of exposure, should be periodically compared with epidemiological data of persons working and residing in the modeled region. Any abnormal rise in illness, miscarriages, birth defects, or deaths should be noted and investigated. Analytical methods will have to be developed for use in the comparison process and to perform the early warning function.

3.2.2 Safety

While the potentials for industrial accidents from oil shale are very similar to those in existing mining and refinery industries, there are some unique areas in which significant safety hazards are inherent.

The hazards associated with underground mining of coal and a number of other minerals are well known. Oil shale underground mining is somewhat unique, however, in that the room sizes for room and pillar shale mines can be up to 60' square, larger than those for coal mining. This is because the shale resource is denser and can support more weight than the corresponding coal resource. The larger room sizes permit the use of larger equipment, and the associated safety issues need to addressed. Similarly, the mine support system to prevent roof collapse must be analyzed by engineers to determine that the mines are adequately protected. More than 3 mm tons of oil shale have been mined to date without any problem.

Another oil shale technology uses rubblized in situ processing which involves little mining, but may represent unique exposure hazards to miners who might be working on a parallel shaft while the adjacent region was being retorted.

Little information is available at the present time, but the refining of shale oil is not expected to result in unique problems when compared to refining of other fossil fuel derivatives. Only the hydrocarbon or trace element mixture may differ, and the problems associated with this have been dealt with previously.

None of these problems seem to be insurmountable and reasonable precautions based on adequate information may be all that is required to protect the workers. The panel chose only to consider those hazards which are unique to oil shale, rather than trying to assess all of the mining and refining technologies.

3.2.2.1 Safety Procedures in Room and Pillar Oil Shale Mines. The oil shale mine providing material for surface retorting with its large underground room and pillar configuration is unique to this industry. The height of the rooms in the room and pillar design may range to 60 feet or more. Coal mines and other types of underground ore and mineral mines are not able to use such large areas, but the shale has greater stability than coal. These large areas permit the use of larger equipment and highly automated mining methods. Because these large areas are unique to mining of oil shale, the problems associated with their use need to be investigated to assure worker safety.

Task 1 - Data on stability of the roof and methods for continuous surveillance need to be developed. Assessments of the safety of the present methods are needed as well as evaluation of the need for additional roof support or extra personnel protection, such as installation of protective screens. Pilot plant studies are indicated to include development of roof stabilization and surveillance procedures. If necessary, requirements for strengthening the roof structure of vehicles, protective screens, and other devices may be needed to decrease the risk.

Task 2 - The high ledges in multilevel room and pillar mines could result in worker and equipment falls. The large-scale construction equipment which can be used in the oil shale underground mines is more difficult to maneuver than the smaller scale equipment generally used for mining. This, coupled with the presence of the deep ledges, could result in dangers to the miners and equipment operators. Poor lighting could contribute to the safety hazard, so visibility studies and development of adequate lighting systems for the area, personnel and equipment are needed.

3.2.2.2 Hazards of In situ Processes. In situ processes may expose workers in nearby underground areas to unique hazards from explosion, fire, and toxic substances during the retorting process. Process gases may also leak to the surface exposing workers and the local population.

Task 1 - Data should be collected to assure adequacy of the barriers between the parallel shafts to protect workers against sheer pressures, explosive forces, and temperatures that must be contained during firing or in the event of explosion, uncontrolled reactions, etc. The permeability requirements of the barriers to hot gases and vapors need to be studied. Precautionary steps should be required to seal around pipes and conduits passing through the barrier and to install proper mine ventilation systems.

Task 2 - Based on the data from Task 1 a model for risk assessment of the adequacy of the containment barrier should be developed.

Using the model, various control technology options such as grouting could be evaluated.

3.2.2.3 Explosivity of Shale Mine Dust. Shale mine dust above the lower explosive limit (LEL) as generated by mining activities may be an explosion hazard. Tosco Corporation is under contract to MSHA to determine the explosiveness of oil shale dust. This study is now near completion.

3.2.3 Industrial Hygiene

As with any industrial process, identification and assessment of the health effects of oil shale and by-products are required. These will, in turn, aid in the setting of standards for exposure and the use and/or development of equipment and procedures for monitoring.

3.2.3.1 Individual Process Evaluation. There is a need to evaluate the various shale oil processes taking into account the geographical siting to determine the adequacy of control of releases of various materials and to identify and quantify the levels of materials in the worker's environment. The high risk areas and employees in these areas need to be identified.

Task 1 - A materials balance study and intensive studies of existing pilot operations including field surveys for particulates, gases, vapors, noise, heat, etc., as related to existing criteria and standards should be conducted to identify the area of risk.

Task 2 - The adequacy of containment controls to bring the ambient workplace concentrations into compliance should be assessed.

If they are found to be inadequate, development of a new generation of controls to revise the process technology must be initiated.

Task 3 - Current awareness of health effects R&D as related to oil shale process stream products and by-products should be maintained. Process technology and controls should be revised and/or updated as indicated to minimize (or eliminate) exposure of workers to recognized hazards.

Task 4 - Exposure should be minimized by initiating human engineering upgrading of the plant. This includes installation of fail-safe controls, relocation of critical or vulnerable subprocesses to minimize the number of employees exposed, upgrading the quality and durability of sealouts and equipment to minimize failure, and regulating frequency of regular required maintenance.

Task 5 - Confirmatory monitoring and surveillance should be conducted. This should include maintenance of precise records on normal process releases, containments and accidental releases for total dust, respirable dust, dust size classification, CO, SO_2, NO_2, arsenic, equipment emissions (diesel), noise, heat, and trace metals.

Task 6 - Monitoring records need to be collated with the medical records of exposed employees. Evaluation of the need for more stringent controls should be periodically undertaken by medical-industrial hygiene and engineering groups. Current awareness of findings (health-exposure data) from other plants and processes should be evaluated for significance to the subject plant and incorporated into the database described in Task 7.

Task 7 - All oil shale exposure and health data should be collected and evaluated by epidemiologists in order to combine small operations into a database adequate to provide significant numbers. Analytical methodologies to serve the various users of the database should be developed.

Task 8 - Information should be collected from other fossil fuel industries on proper industrial hygiene procedures, and a manual should be developed which is applicable to the oil shale industry. This manual should include industrial hygiene measures as well as those for personal hygiene for control of potential hazards.

3.2.3.2 Research and Development Leading to a New Generation of Monitoring and Control Technology. Oil shale technology will introduce into the environment a new series of compounds, some of which may require much more sensitive sampling equipment. The presence of new species of heterocyclic hydrocarbons, possibly more biologically active than those from present petroleum processes, will require new methods of detection (including standards--BAP is not suitable). Intensive study of these species and development of techniques and sampling procedures are needed. Personal monitors to document exposure compared with health effects are one example of anticipated needs.

The more critical contaminants of concern for the enhanced monitoring include: CO, SO_2, NO_x, and hydrocarbons.

4.0 PRIORITY RANKING

As a part of the problem identification exercise each subpanel was asked to rank its problems in order of importance. This listing is included in Table 1. In addition, the panel as a whole met and voted on which of the problems presented by all sub-panels should receive primary attention. The health effects panelists feel that the survey of literature concerning previous epidemiological data on oil shale workers should be reviewed first to identify those effects most likely to result from exposure to oil shale-related materials. Secondly, they strongly supported industrial hygiene studies of each of the two processes likely to be commercialized to (a) identify the adequacy of present effluent/emission controls and, if necessary, when additional control effort should be expended and (b) identify materials likely to result in human exposures thereby providing essential guidance for the conduct of laboratory animal experimentation. Thirdly, the panel felt that the unique safety issues associated with shale mining and in situ retorting should be studied and mitigating measures developed. Fourthly, the panel felt the major initial laboratory experimentation should proceed along two avenues. On the one hand, whole animal studies should be conducted using the materials most likely to be encountered by respiratory and cutaneous exposures. These studies, appropriately conducted, can identify major potential sources of altered human morbidity and morality. The results of these studies may suggest more targeted, mechanistic studies. The other

TABLE 1

RANKING OF HEALTH EFFECTS PROBLEM AREAS WITHIN SUBPANELS

Pulmonary Effects

1. Effects of inhalation of raw and spent shale dust
2. Effects of inhalation of oil shale gaseous emissions
3. Effects of inhalation of refinery products originating from shale oil

Skin Effects

1. Effects associated with skin absorption and penetration by substances associated with oil shale industry
2. Control measures required to minimize effects due to dermal exposure
3. Interaction of shale oil components with other chemicals
4. Effect of underground climate during mining operations on skin
5. Utilization of skin as a model

Genetic and Developmental Biology Effects

1. Identification of potential mutagenic hazard of oil shale process materials
2. Effects of oil shale pollutants on female productive capability and teratogenic effects
3. Effects of oil shale pollutants on male reproductive capability
4. Screening of workers to detect mutagenic/reproductive damage

Behavior and Neurotoxic Effects

1. Behavioral and neurotoxicity tests to measure effects induced by oil shale products
2. Surveillance program to detect neurotoxic effects in oil shale workers
3. Effects of oil shale-related substances on behavior teratology

Epidemiology Studies

1. Prospective Epidemiologic Studies
2. Retrospective studies on previously exposed populations
3. Community Surveillance
4. Integrated epidemiologic assessment of risk to man in and around oil shale facilities

TABLE 1 (Concluded)

Safety Issues

1. Hazards of in situ process
2. Safety procedures in room and pillar oil shale mines
3. Structural integrity of in situ retorts
4. Explosiveness of shale mine dust

Industrial Hygiene

1. Individual process evaluation
2. Research and development leading to a new generation of monitoring and control technology.

avenue of effort should be screening-type studies which use simpler and less expensive tests that can evaluate a larger number of materials or mixtures. The panel acutely recognized the need for closely linking laboratory studies with industrial hygiene studies so that the toxicity data obtained could be used in a meaningful way to assess potential real hazards to workers and the general population.

AIR QUALITY

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OIL SHALE CONFERENCE AIR QUALITY PANEL REPORT

I. INTRODUCTION

Concern over possible air quality degradation has been engendered by the existing research or pilot efforts and the projected major commercial development of oil shale resources in the shale regions of Colorado, Utah, and Wyoming. Emissions during site preparation activities; fugitive emissions from mining, crushing, screening, fuel conversion, and transportation activities; gaseous emissions during the retorting, upgrading, refining, and utilization cycle components; and evaporating emissions from transportation and storage facilities and from water treatment ponds must all be considered in evaluating the impact of the oil shale industry on ambient air quality.

These impacts may be significant not only with respect to the National Ambient Air Quality Standards, but also because of new legislation dealing with the Prevention of Significant Deterioration (PSD) in Federally designated areas. Areas so designated are typically National parks or preserves, and because of the regional implications of air quality alterations and the proximity of some park areas to the oil shale region, potential impacts on these so-called Class I areas must be defined. The regulations regarding the production, utilization, and disposal of an expanding list of toxic materials under the Toxic Substances Control Act (TSCA) and the Resource, Conservation and Recovery Act (RCRA) may also impart significance to emissions from the oil shale resource development

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activities. Future requirements or standards may be even more stringent as more subtle environmental effects become identified.

A review of the various processes and potential pollutant emissions from their energy cycle components yields an identification of four major air quality problem areas, some major collateral technical problem areas and a basic data need. The four major potentially significant air quality problems are:

- anticipation of increased environmental concentrations of toxic materials, particularly the polycyclic organic materials and trace metals and their impacts on human health and welfare
- anticipation of increased production of photochemical oxidants in the atmosphere which will have an adverse effect on human health as well as producing vegetation stress and contributing to visibility degradation
- the expected inadvertent weather modifications, currently not well defined, associated with the emissions from all cycle components of shale oil development
- anticipated degradation of regional visibility from the increased atmospheric loading of primary particulate matter and the production of secondary aerosols.

The major technical problems identified are 1) the lack of definition of the particulate, gases and vapor emissions to the air as a function of the different processes and energy cycle components, 2) the lack of descriptive meteorological models for predicting local and regional impacts over complex terrain, and 3) the lack of adequate understanding of the various chemical transformations which might occur and their rates. These problems and appropriate recommendations are specifically addressed in the concluding section of this report. The basic data need was for more complete air quality baseline information.

II. DISCUSSIONS OF PROBLEM AREAS AND RELATED RESEARCH NEEDS

Because of the dependence of the problem definitions on a quantitative assessment of the source emissions, their rates and specification, a comparative ranking of the problems according to their significance was not possible. The problems were ranked, however, as to whether they were of major or minor importance. Within those categories, priority was assigned to those problems with human health implications.

Problem Area 1

a) Problem Statement: The emissions of toxic materials which may occur from oil shale operations may cause local and regional increases in atmospheric concentrations of these species.

b) Energy cycle components: all

c) Process: all

d) Site: local and region

e) Rationale behind the selection of this problem: Elevated releases of toxic materials into the atmosphere may be experienced on a local and/or regional basis. The materials of concern are trace metals (As, Be, Cd, Hg, Pb, Se, etc.), polycyclic hydrocarbons, heterocyclic sulfur and nitrogen compounds, and others (e.g., cyanides, amines, etc.). The conversion and utilization processes are expected to be the primary contributors of these materials.

f) Pollutants: trace metals, polycyclic hydrocarbons, sulfur and nitrogen heterocyclics, etc.

g) Receptor/population affected: human population and ecosystem

h) Subproblems: effects of single pollutants on human health and terrestrial ecosystems; synergistic and co-factor effects; conversion in the atmosphere to more toxic forms as a function of distance (or time) from source.

i) Data requirements: emission inventory of toxic substances for the oil shale energy cycle

j) Research needs: laboratory studies to investigate chemical reactions that may increase toxicity; develop a transport and diffusion model for predicting the concentrations and deposition of toxic substances over a complex terrain; conduct tracer studies to test model.

Problem Area 2

a) Problem Statement: Elevated atmospheric oxidant levels may be produced on a regional basis by photochemical reactions involving pollutant emissions from all oil shale energy cycle components.

b) Energy cycle components: extraction, conversion, utilization

c) Process: all

d) Site: regional and national

e) Rationale behind the selection of this problem. The emissions of hydrocarbons and oxides of nitrogen, principally from the conversion cycle, react in the atmosphere in the presence of sunlight to produce oxidants which have adverse effects on human health and vegetation. Also, the use of shale oil as a fuel may produce emissions that add photochemically active hydrocarbons to urban atmospheres.

f) Pollutants: ozone, nitrogen dioxide, aldehydes

g) Receptor/population affected: human population, vegetation, materials

h) Subproblems: visibility degradation resulting from formation of secondary aerosols

i) Data requirements: source emission inventory for hydrocarbons (by species) and oxides of nitrogen

j) Research needs: establish a network to make baseline measurements especially in pristine areas for hydrocarbons (by species), oxides of nitrogen, and oxidants (ozone, aldehydes, etc.); develop hydrocarbon ambient monitoring methods; conduct laboratory studies to determine hydrocarbon reactivities for ozone production; develop a transport and diffusion model for predicting oxidant concentrations over a complex terrain; conduct atmospheric spatial-temporal studies to measure oxidants, hydrocarbons, and oxides of nitrogen to test the model.

Problem Area 3

a) Problem Statement: Large-scale development of oil shale resources may cause inadvertent weather modifications which may be significant.

b) Energy cycle components: all

c) Process: all

d) Site: local and regional

e) Rationale behind the selection of this problem: Atmospheric emissions of gases, particles, and waste heat may cause meteorological changes such as: (1) changes in quantity and quality of precipitation, dew and fog; (2) changes in cloud microphysics and dynamics, resulting in changes in storm intensity, frequency and duration; (3) modifications of solar and terrestrial radiation fluxes; (4) changes in atmospheric thermal structure, thermal winds; and the capabilities of the atmosphere to disperse pollutants; and (5) modifications to the concentrations of mesoscale vorticity, possibly leading to more intense dust devils and even tornadoes. The problem, however, is to determine which (if any) of these inadvertent weather modifications are significant.

f) Pollutants: sensible and latent waste heat, particles, radioactive gases, and gases that can react to form particles

g) Receptor/population affected: the ecosystem and population on local and regional scales

h) Data requirements: heat and water vapor emission rates; particle emission rates, size distribution, optical activities, and cloud-element nucleating abilities; gaseous emission rates and optical activities; gas-to-particle conversion rates in the atmosphere as functions of meteorological variables

i) Research needs: establish network to obtain baseline data on (1) cloud microphysics and dynamics in the oil shale area; (2) quantity, quality, and distribution of precipitation; and (3) local thermal winds, radiation and atmospheric thermal structure.

Problem Area 4

a) Problem Statement: Primary pollutant emissions and secondary aerosol production in the atmosphere may cause visibility degradation as a result of shale oil production.

b) Energy cycle components: all

c) Process: all

d) Site: local and regional

e) Rationale behind the selection of this problem: Visibility is considered to be a valuable resource in the area near shale oil operations, including national parks. Emissions may cause significant local and regional visibility degradation in populated and Federally designed Prevention of Significant Deterioration (PSD) Class I areas.

f) Pollutants: secondary aerosols formed by gas-to-particle conversion and primary emissions of particles and light absorbing gases

g) Receptor/population affected: populated area, PSD Class I areas

h) Subproblems: climate modification caused by decrease in insolation

i) Data requirements: the distribution of primary and secondary aerosols in space-time domain, particle size distribution, and chemical composition, concentration of light absorbing gases; background climatology on insolation, cloud cover, ventilation factors, and relative humidity

j) Relationship of data requirements to the problem. The knowledge of aerosol size distributions and concentrations of absorbing gases will permit a determination of the relative importance of aerosols and gases in atmospheric light extinction. Also, the relative importance of aerosol scattering/absorption and gas absorption to coloration effects can be determined if the aerosol composition is known.

k) Research needs: establish a network to make baseline measurements for aerosol characterization (chemical composition as a function of size) and visibility; develop transport and diffusion model for predicting visibility degradation (including coloration) over a complex terrain; conduct atmospheric spatial-temporal studies to measure visibility; aerosol, and gas parameters to test the model.

Problem Area 5

a) Problem Statement: Pollutant emissions associated with all components of the oil shale energy cycle may result in the NAAQS to be exceeded for the primary criteria pollutants (particularly oxides of nitrogen) in the oil shale region. Sulfur dioxide and total suspended particulate (TSP) emissions may also affect nearby Federally designated Class I areas under the PSD section of the Clean Air Act Amendments.

b) Energy cycle components: all

c) Process: all

d) Sites: potential local and regional impacts

e) Rationale: The National Ambient Air Quality Standards (NAAQS) establish maximum time averaged concentration levels of the criteria pollutants. In addition, the Clean Air Act Amendments of 1977 requires the identification of designated areas in which significant deterioration will not occur. Both legislatively established concentration levels stand to be exceeded during the commercial exploitation of the oil shale reserves.

f) Pollutants: CO, hydrocarbons, NO_x, SO_2 and particulates

g) Receptors: human population, terrestrial and aquacti ecosystem and designated Class I areas (PSD)

h) Subproblems: The addition to the atmospheric burden of the primary criteria air quality pollutants will add to the potential for adverse health and welfare effects. Specifically, human health, aquatic and terrestrial ecosystems, and the aesthetics of our environment (visibility) may be impacted.

i) Data requirements:

1) Essential to the assessment of environmental trends, the air quality baseline for the region of interest must be established (includes contribution of natural sources).

2) The total emissions inventory from each energy cycle component of the process (in situ, above ground retort, etc.) under consideration must be quantified if credible predictions of the downwind air quality are to be made.

j) Develop Needs:

1) Develop an air quality modeling capability for the prediction of the spatial and temporal distribution of pollutants in complex terrain on both a local and a regional basis

2) Assess the transformation processes affecting the concentrations of the primary criteria pollutants. The conversion of sulfur dioxide to sulfates, NO_x to nitrates and hydrocarbons to more highly oxidized forms along with the production of secondary aerosols needs to be measured under controlled conditions.

3) Laboratory and field studies are also needed to determine the types and rates of atmospheric removal processes, including dry and wet deposition.

Problem Area 6

a) Problem Statement: Emissions associated with the production and processing of shale oil may result in increased ambient concentrations of radionuclides.

b) Energy cycle components: all

c) Process: all

d) Sites: potential local and regional impacts

e) Rationale: Fugitive dust emissions associated with mine construction, shale extraction, crushing and screening, and disposal; emissions during retorting and upgrading; and combustion of the low-BTU gas for power generation or in a thermal oxidizer can potentially contribute to the atmospheric burden of radionuclides.

f) Pollutants: uranium-238 and thorium-232 and their daughters and potassium-40

g) Receptors: human populations and terrestrial and aquatic ecosystems

h) Subproblems:

   1) In addition to the direct adverse human health implications associated with increased exposure to these radionuclides, elements of the human food chain may also be impacted.

   2) The daughter product radioactivity will rapidly become associated with available aerosol material. The size distribution of the particulate matter will determine its deposition and retention potential in respiratory tract.

i) Data requirements:

   1) An emissions inventory of radionuclides from each energy cycle component is needed as a basis for designing a comprehensive monitoring program. Such a program is dependent on the significance associated with the projected emissions. Particular attention should be given to emissions from the extraction operation (including the overburden and the raw shale) and from the spent shale.

   2) Baseline and background measurement data is needed to assess the trend in air quality and to determine the contribution to the atmospheric radionuclide burden related to on-line development activities.

j) A pilot monitoring program should be designed and conducted to assess the emissions from known and/or suspected sources (fuel cycle components) and in shafts and mines. If warranted (based on the results of the pilot monitoring program) a comprehensive monitoring study should be conducted to assess the local and regional air quality impact from radionuclide emissions. Meteorological and aerosol-size distribution data must also be collected to allow for predictive assessments of the health impact.

Problem Area 7

a) Problem statement: Emissions associated with the oil shale development, especially during the extraction and conversion operations, may result in local concentrations of odoriferous compounds to be elevated.

b) Energy cycle components: extraction, conversion and utilization

c) Process: all

d) Sites: potential local impacts

e) Rationale: Many of the nitrogen and sulfur compounds identified as being potentially released during oil shale extraction, conversion and utilization have objectionable odors associated with them. Although this problem can be classified as a nuisance and is expected to be localized to the areas relatively close to the source of emissions, concentrations of these obnoxious compounds could be quite high.

f) Pollutants: nitrogen and sulfur compounds in the gaseous form and hydrocarbons

g) Receptors: local human population

h) Subproblems: The scrubbing water used for spent shale cooling and moisturizing will contain relatively high levels of dissolved odoriferous gases which will be releasd to the atmosphere.

i) Data Requirements: The emissions inventory of known odoriferous compounds from each energy cycle component for the process under consideration must be known. Although not recommended, if an odor panel were to be convened, then it would be desirable to establish an "odor" baseline for the area as a basis for assessing the contribution of the developing oil shale activity.

j) Research Needs: An assessment of the "odor" potential of each process needs to be conducted and based on measured emission rates and published odor values.

CONCLUSIONS AND RECOMMENDATIONS

Although the air quality panel identified seven problems associated with the oil shale energy cycle, the ranking of these problems as major and minor must be regarded as unsatisfactory at this time. There exists insufficient information and knowledge of many of the atmospheric processes to defend these rankings. The panel also identified certain data deficiencies that must be addressed and technical actions that must be initiated to put these problems into proper perspective in regard to the protection of air quality in the oil shale production area and the surrounding regions.

(1) Common to all the environmental problems was a clear identification of need for valid source emission data for all components and subcomponents of the energy cycle. These data must be specific for chemical species, especially for toxic elements and organics.

Recommendation: Give high priority to the development of techniques for experimentally obtaining valid source emission data, and begin a source testing program.

(2) Also common to all the environmental problems was the identification of a need for a sophisticated transport/dispersion/transformation model capable of predicting air quality in complex terrain using as inputs the source strengths and meteorological parameters. The model currently being used is the EPA "Valley Model," which may not be capable of predicting transport/dispersion/transformation over a complex terrain.

Recommendation: Accelerate work now in progress to model transport/dispersion to complex terrain and have work begin on an application of the complex terrain model to the oil shale production areas and surrounding regions. Such a model must eventually address processes such as formation of secondary aerosols, deposition of gaseous and aerosol pollutants, resuspension of particles, and the contribution of natural sources, in addition to the primary industrial emissions.

(3) Chemical transformations will likely be important in affecting the air quality of the oil shale production and adjacent regions. Of special concern are the hydrocarbon and oxides of nitrogen emissions, which may result in the production of photochemical oxidants. Also of concern is the transformation of toxic organics into chemical classes that exhibit increased toxicity. The oxidation of sulfur dioxide and nitrogen dioxide will yield their corresponding strong acids, namely, sulfuric acid and nitric acid. Depending upon these oxidation rates, dry and wet deposition of acids could occur either in local or regional areas adjacent to the oil shale production area. Recommendation: Begin laboratory experiments to determine reaction pathways and rates in transforming toxic materials and oxides of sulfur and nitrogen into more toxic forms. These experiments must be sufficiently complex to correspond to the mixture of industrial and natural compounds and aerosols expected in the oil shale production region. Also, field experiments need to be conducted on commercial-size units to measure the formation rate of oxidants and aerosols, transformation rates of organics, and formation rates of sulfates and nitrates.

(4) Finally, present monitoring efforts employ EPA recommended techniques and methods that may not be sufficiently selective and sensitive to document the present air quality of pristine areas (present

monitoring systems are primarily designed for compliance purposes and not for basic effects-oriented research).

Recommendation: At least two advanced monitoring stations should be established, one on the prevailing upwind side of the oil shale production region, and one downwind. These stations should employ sensitive methods for the measurement of the criteria pollutants, aerosol-size distribution and chemical composition, and parameters necessary to detect slight changes in air quality leading to weather modification. Data revised from these measurements should serve to determine the requirement for and the scope of a comprehensive monitoring program.

WATER QUANTITY, QUALITY AND AQUATIC ECOLOGY

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WATER QUANTITY, QUALITY AND AQUATIC ECOLOGY

I. INTRODUCTION

Water is a critical limiting resource in those areas of the Western United States where most oil shale is found. It serves as an important recreational and aesthetic commodity controlling, through its quantity and quality, the integrity of both terrestrial and aquatic ecosystems. Alluvial plains and wetlands that are very productive (agriculturally and recreationally) depend upon the maintenance of flow patterns and water quality.

The development of commercial oil shale exploitation is expected to modify both the availability and quality of water in the lands developed. These modifications may result from changes in the hydrologic cycle, increased salinity from mining operations, increased mobilization and transport of trace contamination arising from excavation and conversion of oil shale, and disposal of spent shale.

The potential failure of the available technologies to limit pollutant emissions and to select and develop those processes that optimize water use and availability for competing uses identifies a basic conflict of these technologies with water resources. The purposes of the research activities identified in the following sections are threefold:

(1) To provide rapid information to the technologists to allow development of the most efficient process(es) environmentally as well as economically

(2) To identify and quantify the environmental costs (productivity and aesthetics) associated with oil shale development

(3) To determine critical pathways and concentrations of contaminants mobilized by the oil shale technologies that may reach man and other organisms.

Three subpanels functioned to develop the information for the following sections. They include water quality and quantity, aquatic effects, and aquatic transport and fate. The remainder of this report includes introductory descriptions (by subpanel) and an identification of potential problems and necessary research activities. Early in the discussions of the panel it was agreed that insufficient data were available concerning the organic contaminants that may be released by the various processes and components of the fuel cycle. Hence, it was agreed that discussions would center on classes of organics (e.g., polycyclic aromatics, n-heterocyclics) rather than specific compounds. The latter must wait for further development of the technologies and subsequent characterization. Better information is available concerning trace elements (e.g., AS and inorganic compounds as HCN); consequently, these have been treated in more detail.

A. Water Quantity and Quality

Water quantity and quality will play an important role in the development of Western oil shale and in meeting the water supply needs which accompany this development. The quantity and quality of water may be both a problem and a valuable resource.

Quantity and quality alterations are expected to result from the large withdrawals necessary for oil shale mining and processing. Degradation of water quality may result if adequate controls are not incorporated into the processes of mining, *in situ* retorting, surface retorting, product upgrading, emissions control, cooling, disposition of spent shale and operation of water and wastewater facilities.

Increasing water use requirements will not be limited to those associated with oil shale operations. Municipal and service industry requirements will increase with expanding oil shale development. Locally, the needs of coal development and agriculture may increase. Both quantity and quality will continue to play a critical role in protecting the established wildlife, aquatic species, and natural vegetation.

The water quantity and quality subpanel was primarily concerned with problems related to the quantity, quality, and use of surface and ground water. Selected major problem areas are:

- the availability and quality of water in streams, alluvial valleys and bedrock aquifers
- the legal, environmental, and physical constraints related to withdrawal and use of water
- the management of water withdrawal in terms of use, distribution, and disposal

- the management of water quality degradation related to withdrawal, mine rehabilitation and spent shale disposal

- the impact of water withdrawal on ground water levels, spring and stream flows, and aquifer characteristics

- the impact of plant operations (e.g., in situ retorting, waste water disposals) on the transport of pollutants

- the efficacy of controls, monitoring equipment and procedures.

One of the major problems in the environmental health and safety fields is integration of the disciplines involved in order to provide an overall assessment of oil shale development. Another major problem involves consideration of the long-term effects of oil shale development. For example, spent shale erosion and ground water contamination will produce effects that may take hundreds of years to become obvious.

The objectives of the research suggested to address these problem areas are: 1) to optimize the use of the limited water resources in meeting the needs associated with western oil shale development; and 2) to minimize water quality and ecological stresses imposed by these uses. The scope of this subpanel's objectives includes consideration of surface and ground water and their interactions. Contaminants broadly characterized as toxic chemicals, minerals, and trace metals are considered.

B. Aquatic Effects

The aquatic effects subpanel attempted to address the potential ecological problems posed by changes in the aquatic environment resulting from oil shale development. Major areas of concern identified involve changes in the chemical and physical environment that will be associated with all stages of oil shale development and the ecological implications of these changes. In conjunction with these problems, the subpanel also expressed concern for development and implementation of appropriate biomonitoring techniques and for coordination of present and future research activities to properly evaluate the impact of environmental changes.

The following highlight the major problem areas identified by this subpanel:

- The effects of alterations in water quality resulting from developmental oil shale activities on downstream biota with respect to toxicity, bioaccumulation, and degradation of pollutants subject to release and mobilization need investigation and evaluation.
- Biological sampling and monitoring techniques required to assess the ecological effects of oil shale development need to be developed, tested, and validated.
- Baseline monitoring efforts in oil shale development regions need to be coordinated.
- The effects on biota of physical alterations in aquatic habitats need investigation.
- The secondary effects on aquatic ecosystems of urban population expansion need investigation.
- The effects on marine and estuarine systems from the use of oil shale products need investigation.

C. Aquatic Transport and Fate

Development of an oil shale industry as an additional energy source for the U.S. will be accompanied by many environmental problems. The aquatic transport and fate subpanel was particularly concerned with problems related to the release of various physical and chemical constituents to the environment. Some releases will have minor or no effect upon aquatic ecosystems, but others may be of significant concern. Thus, it is imperative that we gain a thorough understanding of the fate and transport (routes, rates and reservoirs) of constituents which reach aquatic ecosystems from all aspects of the energy cycle in addition to an understanding of those already present in the environment. Physical and chemical constituents, originating naturally or from process technology, will find their way to underground and surface waters in many ways. Some of these constituents will be of concern because they may directly impact aquatic ecosystems and/or enter food pathways leading to man (Figure 1). This subpanel addressed the following aspects of the problem:

- identification of the various physical, organic and inorganic constituents which reach the aquatic environment from the different technologies and fuel cycle processes

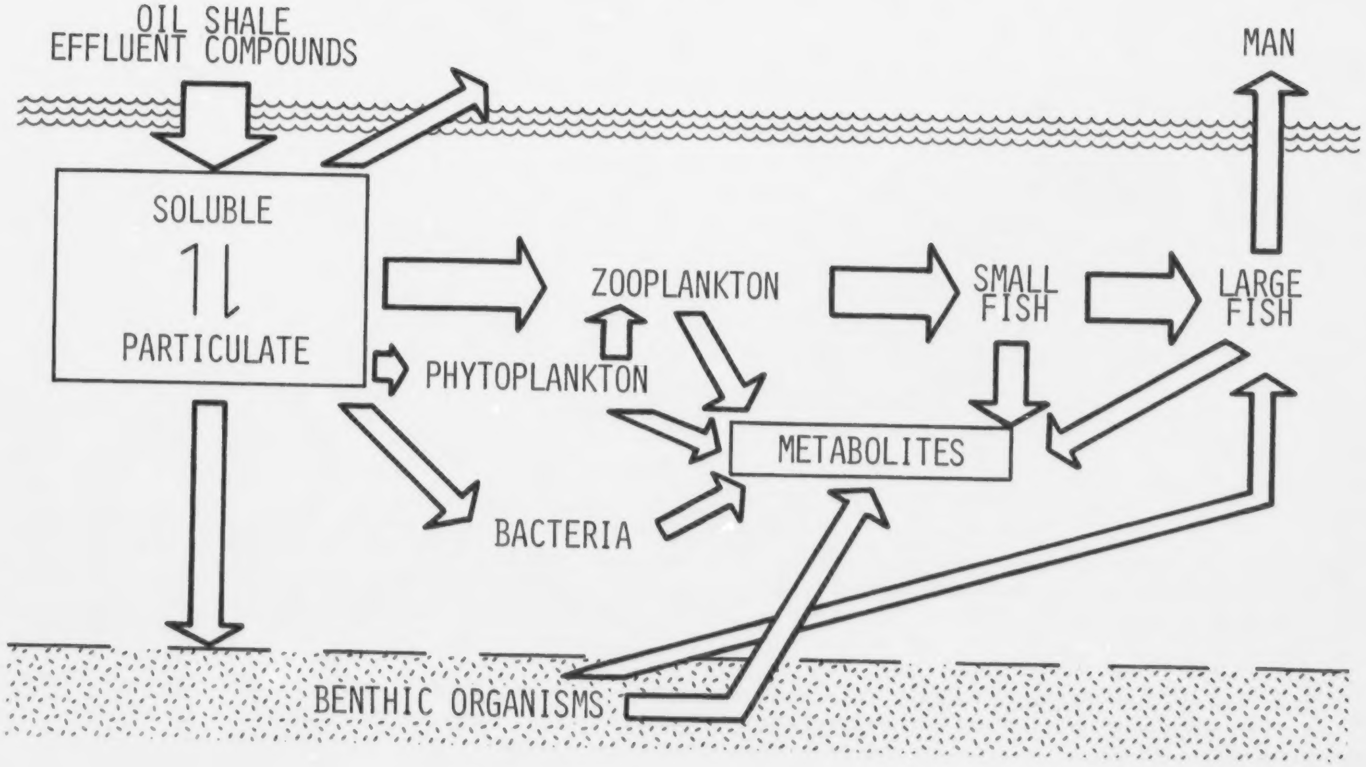
OIL SHALE
EFFLUENT COMPOUNDS
MAN
SOLUBLE
PARTICULATE
ZOOPLANKTON
PHYTOPLANKTON
SMALL
FISH
LARGE
FISH
METABOLITES
BACTERIA
BENTHIC ORGANISMS

FIGURE 1
TRANSPORT ROUTES
OF OIL SHALE EFFLUENT
COMPOUNDS THROUGH AN
AQUATIC ECOSYSTEM

- determination of the transport and fate of these constituents in aquatic environments as a result of the development of an oil shale technology.

It is obvious that the first aspect of the problem is basic to the second, and most likely, will be addressed by another workshop group (source characterization). In essence, we need to know which contaminants are of utmost concern in terms of potential transport and fate via aquatic systems. Once these constituents are identified, it is necessary to determine how and at what rates they are transported, transformed, and become either accumulated in or eliminated from the aquatic systems. Inherent in this major problem area is a knowledge of the governing functions of various environmental parameters upon the transport and fate of these constituents.

An understanding of the processes is useful because (1) target organisms for effect studies can be selected; (2) daughter compounds appropriate for study can be defined (input chemicals may be inappropriate for monitoring or effects studies), and (3) sinks of toxicants can be identified for monitoring and effects studies.

PROBLEM AREAS

WATER QUANTITY AND QUALITY

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II. PROBLEM AREAS

A. Water Quantity and Quality

1. Problem Statement: The amount of water available for oil shale development must be determined. In the water-limited oil shale areas, a knowledge of the water available is an absolute basic requirement for prudent utilization of this resource. Some preliminary data suggest that, for example in Piceance Basin, the stored ground water could support an oil shale industry of several hundred thousand barrels/day for several decades. Estimates of the amount of ground water in storage in the Piceance Basin range from 2.5 million to 25 million acre-feet.

A thorough management program must consider the total regional water supply and demand. The physical supply of surface water is reasonably well known and on the basis of acre-feet per year available represents a fixed amount. However, since the fixed amount is less than anticipated potential demands, this resource must be utilized as efficiently as possible. The physical supply of ground water is not well known, but is probably large in relation to short term (10-100 year) needs. The ability to predict ground water movement in response to oil shale mining stresses is essential for evaluation of this resource.

In terms of the total water supply, consideration should be given to the following closely related factors:

- local and imported surface and ground water supply
- increasing the supply through management techniques -- efficient use, recycling, etc.
- effect of constraints -- legal, water quality, location, environmental, etc.
- effect of "mining" ground water on surface water supply.

Methods for reducing the impacts of oil shale development on water resources must be employed. Because zero discharge will impact the water supply available for downstream users, it should be examined on a site by site basis. Evaporation from surface reservoirs in the Colorado drainage is now 2 - 3 million acre-feet per year and may reach 5 million acre-feet per year with future reservoir development. Methods for oil shale industry location, design, and operation are needed to minimize such losses.

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Information Requirements	Research Projects
• Knowledge of the supply of ground water available for oil shale development is needed; the following are specific requirements: - definition of aquifers - delineation of areal distribution and thickness - determination of aquifer characteristics including coefficient of storage	• Drill test wells and conduct aquifer testing. There are test wells available but most need companion wells so that testing can attempt to predict aquifer properties such as storage.
• Knowledge of the occurrence and movement of ground water is needed.	• Develop a ground water model which will allow extrapolation of data, point to data needs, and provide input to the evaluation and management of this resource. Research on flow in fractured media is needed.
• Knowledge of the supply of surface water available for oil shale development is needed. All available physical data (e.g., stream flow records) must be identified.	• Conduct a systems analysis using all available data and develop water use optimization schemes for the basin-wide region.
• The extent to which impoundments (designed to capture runoff) will reduce stream flow in downstream areas must be determined.	• Examine and evaluate methods which can be used to reduce the impact of impoundments on water availability (e.g., using compensatory flow from dewatering or from treatment plant operations).
• The extent to which ground water withdrawals will deplete surface water supplies needs to be determined.	• Determine the effect of ground water withdrawals or steam discharge using computer modeling supplemented with field data.

2. Problem Statement: The quality of water available for oil shale development must be determined. The quality of surface and ground water governs what water uses (as is) may be and what treatment will be required, both for use and for release downstream.

Information Requirements	Research Projects
• present water quality	• Coordinate existing water quality data sources with water quality monitoring programs and with needs for additional sampling.
• future water quality	• Conduct a complete systems analysis using existing water quality information to construct a realistic model capable of predicting future water quality conditions. The model must be comprehensive; the effects of oil shale development and other activities (e.g., coal development, headwater diversions, evaporation from reservoirs) on future water quality must be determined.

3. Problem Statement: There are constraints, most of which are imperfectly known on the use of physically available water resources for oil shale development. The following are major areas of concern:

- Legal constraints include state, interstate, and international commitments downstream; federal and state (unresolved) interests, including Indian rights.

- Economic constraints include the construction and operation of diversion and conveyance structures; the treatment necessary for water use and wastewater discharge because of poor existing water quality; the cost of reinjection or other disposal method. Well yields and mine dewatering are a local constraint.

- Environmental constraints include adverse effects on the quantity and quality of streams, springs, and wells; meeting regulatory requirements.

Because of legal constraints, water resources in the arid West are frequently not prudently used; for example, the "use or lose" syndrome sometimes promotes wasteful operations. Legal constraints on surface water-ground water relationships often prevent optimum development of large supplies of ground water.

Present utilization of physically available water supplies cannot be achieved without a thorough knowledge of the economic and environmental constraints.

Information Requirements	Research Projects
• legal constraints on utilizing water for oil shale development	• Identify existing legal constraints and also those that are not yet "legally settled." Within the laws extant, it appears that some flexibility is available for optimum water utilization in a scientifically sound manner. Explore such avenues.
• economic and environmental constraints on utilizing water for oil shale development	• Identify the economic and environmental constraints and determine the interactions of these and oil shale development stresses.
	• Given the total water supply (see II A1), apply different economic and environmental scenarios to determine the limiting factors and develop a management plan for water utilization.
• Specific data on the costs of water handling as constrained by legal and environmental factors are needed.	

4. Problem Statement: There are management problems associated with ground water withdrawals, water usage, distribution, and disposal. Dewatering of underground retorts will

involve maintaining large and consistent pumping rates for long time periods and disposing of pumped water by reinjection or discharge to a stream channel. There have been considerable problems in keeping large pumps operating. There may be problems with treatment of pumped ground water prior to reinjection and with maintaining injection wells so that they can accept the treated water at desired rates. In order to manage a ground water basin, knowledge of the potential for utilization of the different quantities and qualities of water available is needed so that ground water will be used on a rational basis (i.e., the uses of potable water versus brackish water versus saline water for local commercial developments). Competition for water depends on the quantity and quality of the resource.

Information Requirements	Research Projects
• Pumping and injection or disposal rates for ground water and characterization of pumped ground water are needed.	• Monitor water levels in observation wells. Monitor pumping and injection or disposal rates. Use monitoring results to evaluate procedures and to recommend modifications.
• Information on ground water quality and quantity in oil shale areas is needed. Data are needed on redox conditions underground and the source of calcium injection well problems.	• See II A1 and II A2. Possible areas of study are microbial activity, redox changes with pumping and solubility, stability problems concerning iron oxyhydroxide precipitates and borehole dissolution effects.
	• Define the utilization potential for the available water resources.
• Information on ground water and also oil shale effluent treatment costs is needed.	• Evaluate treatment costs for the available water resources as a function of utilization. Compare pre-treatment and oil shale effluent treatment costs.

5. Problem Statement: The optimal use of water resources in areas of oil shale development depends on both the quantity and quality of water as well as efficient utilization. Water can be used several times if each subsequent use requires lower quality water or if treatment is provided, either before or after each use. Efficient water utilization is also effective in reducing waste flow. Effective wastewater treatment and disposal is necessary to protect the integrity of water in oil shale development areas.

Information Requirements	Research Projects
• Data and information are needed on the following wastewater treatment and disposal alternatives: - the use of soils for waste treatment - the use of mines for waste disposal - the use of conventional and advance waste treatment techniques - the use of wastewater to stabilize spent shale piles.	• Determine the cost and effectiveness of these wastewater treatment and disposal techniques for wastes from oil shale developments.
• Information is needed on water conservation and reuse techniques.	• Identify ways in which water requirements can be reduced. Investigate the use of wastewater for irrigation. Examine sequential use (multiple reuse) according to decreasing quality requirements.

6. Problem Statement: Large withdrawals of ground water will have an effect on the amount of ground water in storage and on the amount of ground water discharged from storage to become stream flow. Heavy long term pumping of ground water will lower the water levels in wells over wide areas; this will result in (1) diminished spring and stream flow and irrigation supply; (2) possible compaction of the aquifer accompanied by subsidence; (3) possible reduction of pressure in commercial gas sands at the bottom of the Green River Formation; (4) stream channel erosion by discharge of pumped ground water; and (5) reduction of the available water supply by consumptive use.

Information Requirements	Research Projects
• water levels	• continue current research investigations
• spring and stream flow	• continue current research investigations
• bench marks (by surveying)	• monitor twice a year in areas of large water-level changes
• gas pressure changes (from oil companies)	• obtain reports from oil shale companies
• stream channel erosion	• continue current monitoring
	• use the results from the above projects to evaluate future changes
• The extent to which mine dewatering will lower water tables, lower piezometric surfaces of aquifers, and reduce stream flow must be determined.	• examine and evaluate the following methods which can be used to reduce the impact of mine dewatering on ground water availability: - reinjection of effluents and surplus water - recharge impoundments along appropriate reaches of streams

7. Problem Statement: Changes in surface and ground water quality will occur to varying degrees as a result of oil shale development and indirectly from increases in the population and supporting service industries. In order to optimize utilization of this limited resource, the changes in water quality resulting from these activities must be evaluated. The effectiveness of proposed controls for all facets of oil shale development are now largely uncertain. As the various proposed processes are developed, concomitant research into their effects is necessary to minimize environmental stresses while optimizing energy production. The impact of the various activities associated with western oil shale development can only be measured after determining the transport and tranformation characteristics of contaminants. Since the majority of the heat created during retorting will be vented to the atmosphere or to wastewater effluent streams, the impact of the total heat load needs to be evaluated in terms of microclimatology and surface and ground water effects.

Information Requirements	Research Projects
• Data on the contribution of toxic chemicals, minerals, and trace metals from mine dewatering, surface and in situ retorting, boiler blowdown, cooling towers, dust control, spent shale piles (stability, erosion, leaching) and shale pile impoundments are needed.	• conduct field studies to measure water quality changes resulting from all aspects of oil shale production (including the disposal of wastewater); see II A2, II C1 and 2
• Information on the quantity and quality of effluents resulting from increased municipal and support service industries is needed.	• establish waste characteristics, develop models for predicting the effects of various growth and waste disposal scenarios, and conduct field studies to verify predictions

• Data are needed on the transport and transformation of contaminants in the surface, subsurface and atmospheric environments (e.g., reaction rates, equilibria constants, solubility coefficients, mixing and diffusion constants).	• conduct laboratory column and shaker tests to determine sorption isotherms; evaluate geochemical investigations, air and water diffusion tests, leaching and stabilization tests and organic, aerobic and anaerobic degradation tests for selected contaminants and model transport kinetics; see II Cl and 2
• Information and calculations are needed on heat loading and balance.	• conduct a heat balance study for different levels of oil shale development and model heat flow through the system

8. Problem Statement: The effectiveness of controls to reduce the impacts of oil shale development on water quality should be monitored and evaluated. After retort chambers of in situ operations have been abandoned, ground water can enter the chambers and dissolve and move pollutants to aquifers and eventually to points of surface discharge. This may be the most serious long-range environmental problem of in situ operations. Monitoring approaches for assessing the problem and control measures need to be evaluated.

Information Requirements	Research Projects
• The following information is needed to evaluate the effectiveness of spent shale slurry grouting of in situ retort chambers in controlling water quality: - hydraulic characteristics to retort chambers after retorting is complete but prior to grouting operations	• conduct studies to obtain and evaluate the identified information requirements; conduct lysimeter studies with spent shale from in situ operations to determine its characteristics (e.g., compaction, permeability); sample and analyze water quality

- acceptability of retorted chambers for receiving grout - hydraulic characteristics of chambers after being treated with spent shale slurries. - design criteria for wells to sample retort chambers and adjacent rock materials - chemical descriptions of effluents from retort chambers through time to show water quality changes as a result of the control measure	
• Information is needed on the economic and engineering feasibility of grouting of retort chambers in the absence of grouting operations, on subsidence-related characteristics of rock layers overlying retort chambers, on support strength provided by slurry additions and on the time involved in slurry set-up.	• evaluate the ability of slurry grouting of in situ retort chambers to control subsidence and subsequent alterations in ground water quality; design a means for monitoring actual field applications
• The following information on leaching from abandoned in situ chambers is needed: - leachable pollutants in retorted chambers (identification and quantification) - transport of pollutants in ground water	• evaluate information obtained and develop a methodology for monitoring the effects of leaching from abandoned chambers on ground water quality; include recommendations on the design of sampling wells, sampling frequencies, and on pollutants to analyze; develop a predictive model

- hydraulic characteristics of abandoned retort chambers
- ground water flow characteristics
- design and cost of observation wells

- Information is needed on measures to control the quality of water resulting from oil shale conversion and spent shale disposal

- describe and evaluate control structures and systems that have been used and/or are proposed for use; these might include: 1) filling retort with an inexpensive adsorbent such as bentonite 2) collecting, treating and reinjecting the leachate 3) forming a grout curtain around the retort and 4) mine design to reroute the water; include recommendations for improvements in systems and facilities

9. Problem Statement: Quality assurance/quality control on the water quantity and quality data collected must be adequate for the intended use of the data. Data that are not of sufficient accuracy and precision may result in: (1) perturbations that are either an artifact of the data collection system or are not detected and (2) misinterpretations of the data or erroneous conclusions.

Information Requirements	Research Projects
• Information from data users on the required level of accuracy and precision and an identification of the "state-of-the-art" is needed.	• determine an acceptable level of accuracy and precision; prepare quality assurance/quality control procedures; develop the accurate analytical techniques

- establish a system of standards so that laboratories doing water quality studies can be evaluated.

B. Aquatic Effects

1. Problem Statement: Downstream biota may be affected by changes in water quality resulting from oil shale development. The effects of "whole" effluents, fractions of "whole" effluents (such as organics, heavy metals, PAH's, etc.), individual contaminants and treated effluents from oil shale developments on aquatic ecosystems are potentially severe. The survival, behavior, growth, and reproduction of each trophic level may be affected. Toxic components may interact in a synergistic, additive or antagonistic manner. The effects on individual organisms and populations may result in changes in community structure and function. As a result, a substantial research effort must be maintained concerning the toxicity, degradation and bioaccumulation of contaminants in aquatic organisms and communities.

Information Requirements	Research Projects
• chemical characterization of effluents and treated effluents	• expected from water quantity and quality subpanel, see II A7
• effective concentrations of effluent constituents in aquatic ecosystems following treatment and in-stream degradation, dilution, adsorption, etc.	• expected from water quantity and quality and transport and fate subpanels, see II A7 and 8, II C1 and 2
• identification of communities and species that are likely to be subjected to effluents	• from II B2 and II B3
• toxicological characterization or process effluents from various oil shale development alternatives	• establish a program for downstream baseline sample collection and preservation

- conduct an extensive literature review and compile information (e.g., toxicity, bioaccumulation potential) on the effect of identified effluent constituents (including chemical classes) on aquatic biota
- use screening bioassays to evaluate the acute and chronic toxicity of "whole" effluents (e.g., plant process water, spent shale, leachate, contaminated groundwater), effluent fractions (organics, inorganics, PAH's, etc.), individual contaminants, and treated effluents on key aquatic organisms and communities
- conduct bioaccumulation and degradation screening tests for effluent constituents using such methods as: n-octonal/water partitioning HPLC retention time, actual biotic component exposure tests and microbial degradation tests to identify compounds which have serious persistence and bioaccumulation potential

• An identification of the chemical, physical, and biological parameters that mediate the cycling of constituents and of the interactions which occur is needed.	• determine the influence of the various physical, chemical, and biological mediators on the cycling of constituents and also determine if and how the mediators and/or constituents interact in governing the cycling of constituents
• A determination of the transfer coefficients of the constituents is needed.	• using the data from all of the above projects, construct predictive models of the rates of cycling of the constituents through aquatic ecosystems.

- development, testing, and evaluation of models that predict the outcome of alternative oil shale processes and treatment systems in terms of toxicity, bioaccumulation, etc.

- for contaminants which have been identified in toxicity and bioaccumulation screening tests as potentially serious environmental threats, conduct sublethal toxicity tests on key populations, predator-prey, food web or competitive interactions to determine effective concentration

- construct and validate predictive models utilizing information from individual research projects concerned with the effects of water quality on downstream biota.

2. Problem Statement: Appropriate sampling techniques for baseline aquatic monitoring must be developed and verified. Conventional sampling and monitoring techniques successfully utilized in humid regions may have limited application in arid and semi-arid oil shale development regions. Current standard methods for macrobenthos, periphyton, and fish sampling seem to be inadequate and/or inapplicable in the depauperate stream ecosystems which are found in the oil shale development areas. Where oil shale development will occur, research is needed to identify those measurement techniques which are appropriate for use in the ranges of aquatic ecosystems potentially impacted by oil shale development activities in order to assure acquisition of high quality data in the most cost effective manner.

Information Requirements	Research Projects
• identification of biological sampling and monitoring techniques which are applicable to a variety of stream habitats potentially impacted by oil shale development activities (e.g., highly productive, stable stream environment vs. depauperate, unstable reaches characterized by patchy distribution of stream organisms)	• develop, test and validate biological (macroinvertebrate, fish, periphyton) sampling techniques which are appropriate for incorporation into comprehensive monitoring designs for streams in the semi-arid and arid regions potentially subject to oil shale development impacts; the monitoring designs developed should take into account annual cycles, climatic (e.g., dry year), and other environmental extremes, and the results should be subjected to appropriate quality assurance procedures.

3. Problem Statement: Baseline monitoring for on-site and downstream aquatic ecosystems needs to be coordinated. Presently, existing monitoring studies in potentially affected aquatic ecosystems appear uncoordinated. Many investigators are collecting baseline data with little awareness or intergroup coordination. Development companies, government and independent researchers are all concerned with evaluating baseline ecosystems, unfortunately, usually through the use of different sampling and analysis procedures. This allows for little comparison of results. Needless duplication of effort may be spent evaluating some factors while other critical baseline studies are being neglected. Existing and future baseline monitoring studies in potentially affected areas need to be coordinated to overcome both duplication and neglected research and to ensure maximization of data output from available funds.

Information Requirements	Research Projects
• Data on the "best available" sampling and monitoring methods are required.	• see problem statement II B2

• identification of planned oil shale development activities by watershed or region and of all researchers doing ecological and other baseline monitoring in the region	• conduct an integrated assessment by region (e.g., Piceance Basin) and by process technology which coordinates input from all investigators; coordination should be established early to promote data exchange, sample exchange, etc., and to obtain maximum value from the baseline studies. This requires compatible methods, data reporting, and analysis procedures. To accomplish this project, the responsible federal and state agencies and other parties should appoint and develop support for a coordinator.

4. Problem Statement: An assessment of the end use impact of shale-derived fuels on estuarine and marine biota is needed. Utilization of shale oil may cause the release of hazardous elements and compounds into the estuarine and marine environment. Because of the fragile and productive nature of these marine ecosystems, a thorough assessment of the toxic effects of shale oil by-products is necessary. Since the Navy will be the first major user of shale oil, it is anticipated that these fuels will enter the environment from combustion, spillage, runoff, bilge water, etc.; therefore, research in this area will provide data on possible environmental effects before large scale utilization of shale-derived fuels takes place. There is little available toxicity information on the effects of shale-derived fuels on estuarine and marine organisms or on the potential for carcinogens and other toxicants to reach man through seafoods.

Information Requirements	Research Projects
• Toxicity and bioaccumulation data on the fate and effects of shale-based fuel constituents on marine organisms are needed.	• study the effects of fuel constituents on marine organisms and the routes, rates, and reservoirs of these contaminants in the affected ecosystem

• Information is needed on the potential for toxic, mutagenic, carcinogenic, and teratogenic components of shale oil to bioaccumulate in marine food webs.	• determine the fate of refined oil shale fuels in the marine environment • determine the potential for food web accumulation of toxic components of shale-derived fuels (consider seafoods and effects on man)
• Data are needed on the effects of shale-derived fuels on the structure and function of potentially affected marine and estuarine communities.	• perform tiered testing system of bioassays including: life cycle studies, settling plankton communities, biochemical cycling, etc.

5. Problem Statement: Oil shale development can adversely affect aquatic ecosystems through physical alteration of habitat. Stream and river hydrographs will be altered as a result of plant and mine construction, extraction, conversion, and also off-site activities (e.g., diversions, dams, channelization, impoundments). The effects of total suspended solids transport, sedimentation and scouring, and changes in substrate size in conjunction with altered hydrographs may result in problems involving invading terrestrial environment, the proportion of lentic and lotic habitat and effects on aquatic biota.

Information Requirements	Research Projects
• Historical surface hydrology information emphasizing stream and river hydrographic data for potentially impacted drainages is needed. The timing, duration, and volume of peak and minimum flows and changes in mean annual flow are needed.	• see II A1

• Information of development companies' projected operating plans including groundwater drawdown, timing, and amount of discharge, etc., is needed.	• develop predictive hydrologic models that use historical and company information to define potential extremes for drainage basin hydrographs when oil shale development is implemented; use models to predict the ranges of expected changes in physical parameters
• Baseline data on biota in potentially affected aquatic ecosystems are needed.	• see II B2
• Information on the effects of potential alterations in habitat on aquatic community structure and function and on representative important species is needed.	• conduct field and/or laboratory research using techniques such as manipulation of substrate size, flow regimes, sedimentation, etc.

6. Problem Statement: There will be secondary effects on aquatic biota due to the increased human population associated with oil shale development. The human population increase is expected to result in increased recreational pressure, water demand for human use, waste (sewage) disposal, housing development and non-point-source contaminants (e.g., nutrients, pesticides). Possible attendant effects on the aquatic habitat include reductions in flow due to the increased water demand, and sedimentation, channelization, and a reduction in wetlands habitat due to the increased housing development.

Information Requirements	Research Projects
• The projected growth in human population associated with oil shale development is needed.	

• Information is required concerning the increase in water demand; the nature and the amount of sewage, non-point source contaminants, solid wastes generated; the increase in recreational pressure and the extent of wetland habitat loss.	• conduct field research to determine the cumulative effects of altered water quantity and quality, increased recreational fishing, and habitat disturbance on fisheries production and on the carrying capacity of the environment • conduct an environmental assessment ("armchair research") and prediction of the effects of increased human population on the aquatic biota; recommendations for mitigation should be emphasized.

C. Aquatic Transport and Fate

1. Problem Statement: Baseline characterization which involves an identification and quantification of the various physical, inorganic and organic constituents which will reach the aquatic environment as a result of oil shale development is needed. Constituents are expected to enter the environment from natural sources and from oil shale planning and development, extraction, conversion, and utilization. Accurate, reproducible qualitative and quantitative measurements are necessary in order to establish existing environmental conditions, including the fate and transport of physical and chemical constituents, prior to any activity relating to oil shale development. In order to compare preoperational fate and transport with post-operational fate and transport, a preoperational data base is required. Without the preoperational data base, possible adverse enviromental effects cannot be measured and related to oil shale development. The development of an oil shale industry will result in a certain amount of dust released to the environment and vegetation removal will result in increased sediment erosion. The impact on the aquatic environment resulting from development needs to be evaluated. It is anticipated that during the extraction of shale oil, retorted and spent oil shale will be disposed of above ground. Leaching of water through this material will result in higher concentrations of certain inorganic elements than that expected in the leachate from unretorted oil shale. Materials resulting from the conversion process may be subdivided into two categories: (a) surface disposal piles consisting for the most part of retorted oil shale and (b) *in situ* retorted oil shale. The ultimate significance of each depends on the availability of water for leaching. Considering the abundance of ground water in the *in situ* regime, leaching of *in situ* retorted oil shale and subsequent migration to surface streams may pose a greater environmental hazard than surface disposal piles which are more readily controlled.

Shale oil contains arsenic which must be removed prior to refining. It has been proposed to remove this arsenic with ion exchange resins and to dispose of the resins with the retorted oil shale in disposal piles. Consequently, the amount of arsenic leached from the disposal piles which ultimately will reach aquatic environments must be determined. The carbonaceous residue of oil shale retorted by such processes as TOSCO II and Paraho contains a significant quantity of energy. It has been proposed to remove this residue by a steam extraction process. The removal of the carbonaceous residue may affect the mobility of constituents in the retorted shale, especially those inorganics which may have been immobilized by the residue, as well as those organics which may be removed by the steam extraction process.

Information Requirements	Research Projects
• A physical (e.g., temperature) and chemical (e.g., chelating agents, heavy metals) data base is needed prior to any environmental disturbance.	• Generate qualitative and quantitative data which will establish accurately the environmental conditions prior to any oil shale development; complete statistical treatment of all data is essential for adequate evaluation and effective use of the data by decision makers.
• The physical, organic and inorganic constituents which enter the aquatic environment from the development and construction of oil shale industry facilities must be identified and quantified.	• expected from the source characterization panel
• An identification of the materials originating from oil shale extraction and their distribution in the aquatic environment (i.e., fugitive dust from mining, transport, and crushing; disposal of unretorted shale) is needed.	• expected from the source characterization panel
• An identification and quantification of the physical, organic and inorganic constituents in unretorted shale and a characterization of the leachate from the unretorted shale are required.	• conduct laboratory leaching experiments on unretorted shale

• An identification and quantification of the constituents which may enter the aquatic environment from the interaction of water with the materials resulting from the conversion process are required.	• conduct laboratory shaker and column leaching experiments to characterize leachates from different materials • lysimeter studies are necessary, where possible, to better model field conditions • conduct field studies on *in situ* retorted zones to monitor the water-shale interaction and the migration of constituents
• Information concerning the mobility of arsenic in retorted shale disposal piles is needed.	• identify the form of arsenic which will be present in a retorted shale disposal pile • conduct leaching experiments to determine the solubility of arsenic
• An identification of the process to be used in decarbonization of retorted shale is needed.	• produce decarbonized material by the identified process, perform laboratory leaching experiments (shaker and column) using the carbonized shale and its decarbonized equivalent, and compare the composition of leachates
• An identification of the composition of shale and crude oil is needed.	

• An identification of the constituents released from shale oil during refining, transportation, and utilization and a determination of the potential environments affected are needed.	• see II B4

2. Problem Statement: A determination of the fate of constituents released to the aquatic environment as a result of all aspects of oil shale technology is necessary. The fate of physical, inorganic and organic constituents and the factors that mediate their routes and rates of movement and reservoirs need to be determined. High priority organic constituents are: pyridines, anilines, quinolines, n-heterocyclics and polycyclic aromatic hydrocarbons. High priority inorganic elements include arsenic, boron, fluorine and selenium. Mercury, zinc, molybdenum, cobalt and cadmium are probably of lesser importance. It is possible that certain inorganic constituents may become higher priority items for study than some of the organic constituents as a result of their occurrence in unusual quantities in certain ecosystem components. The fate of physical constituents, such as silt and sediment particles, is of concern. The physical constituents may be intimately associated with some of the organic and inorganic elements or compounds of concern, and their relationships must be considered from both aspects. Successful completion of all aspects of these research areas should permit the construction of predictive models which define the transport and fate of constituents in aquatic ecosystems.

Information Requirements	Research Projects
• A determination of the chemical form of the constituents, including transformation and degradation products is needed.	• characterize the physical, inorganic, and organic constituents which will enter the aquatic environment
• Knowledge of the routes of movement of the constituents through aquatic ecosystems is needed.	• determine the natural occurrence of constituents in ecosystems and delineate likely routes of transport

TERRESTRIAL EFFECTS

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TERRESTRIAL EFFECTS

1.0 INTRODUCTION

Development of Western Oil Shale resources may significantly impact terrestrial ecosystems. The first task of the Terrestrial Effects Panel was to identify, state, and prioritize these potential problems based upon: review and discussion of current research completed or underway in the oil shale region; review of recent projections(1) of specific and generic problem areas in which additional understanding of the present and developing technology seems warranted; and independent review of several matrices describing the pollutants and disturbances associated with each stage of the full energy cycle for the various types of shale oil technologies.

The panel was asked to consider a wide range of potential consequences that could result from full development of the oil shale industry. These included geological considerations such as subsidence and slumping, chemical issues such as the uptake and transfer of trace elements, and biological factors such as plant and animal susceptibility to toxic gaseous emission, consequences for wildlife, improved standards of ecological baseline measurements, and secondary effects induced as interactions within terrestrial ecosystems.

Review and discussion of current research in the oil shale region, closely related assessment programs (e.g., coal), and draft

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(1) DOE, EDP, and EPA Preliminary Assessment and other material and information available at the workshop.

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research projections of DOE identified about 20 generic problem areas in which additional understanding of the consequences of the present technology seems warranted. Further work on these problem areas led to the coalescing of some, and the interfacing of others with proposals from closely related panels. Information on the remaining topics is grouped by 'problem area.'

1.1 The Approach

The full panel first met as a whole and provided opportunity for panel members to describe their individual areas of expertise, their current research efforts and their identification of potentially important impact areas. This resulted in the preliminary identification of specific problems. Based upon this preliminary identification, and the disciplinary mix of the panelists, the full panel broke into two subpanels (abiotic and biotic) to systematically examine the matrices of pollutants and disturbances arrayed against each step of the energy cycle. This step identified and prioritized potential consequences associated with full-scale development of the oil shale industry.

Following this activity the full panel reconvened to discuss the problems and to organize several working groups, to examine identified problems in depth, and to prepare more formal statements of: (1) problems; (2) associated data and information required to address the identified problems; and (3) research projects required to generate the needed data and information. The working groups covered the following areas:

- mine dewatering and water quality
- subsidence
- air pollution
- management of raw and processed shale
- wildlife management
- baseline information
- ecosystem dynamics

Separation of the research needs into a series of projects required a very complex mixing and splicing of disciplines and training. The panel took some pains to emphasize, however, that even when these specific results are available, a great need will exist for further evaluation of whole-system properties and responses. Research on this topic has been proposed, and in its early stages, it will help guide experimental programs on critical ecosystem processes. However, the entire assessment process should be reviewed as a "development continuum," interacting with the emergence of new technology and continuing throughout the full operation period.

The potential terrestrial effects of oil shale mining cover a wide range. Such impacts could involve:

- subsidence due to underground extraction, in situ retorting, or mine dewatering
- adverse impacts on wildlife and livestock due to gaseous, aqueous, and solid effluents
- drying up of seeps, springs, and other sources of water for wildlife and livestock

- erosion, instability, and spontaneous combustion of raw and processed shale piles
- disturbance of wildlife habitat due to construction, operation, and recreational activities of the associated work force

Many, and hopefully all, of these impacts can, if sufficient scientific knowledge is available, be controlled or avoided by proper design, site selection, management, and other methods. It was the purpose of this panel to attempt to define the approaches to attaining this knowledge.

1.2 Representation on the Panel

The panel contained a rich and varied mixture of people with wide experience in oil shale and environmental research including representatives from industry and regulatory agencies. The latter provided a vital element of practicality. A wide range of backgrounds, organizational affiliations and professional disciplines was represented. The following organizations were represented, and a listing of panel members is contained in Appendix A.

Federal Agencies

Department of Energy, Office of the Assistant Secretary for Environment

Department of Energy, Pacific Northwest Laboratory

Department of Energy, Lawrence Livermore Laboratory

Department of the Interior, Fish and Wildlife Service

Department of the Interior, Western Energy and Land Use Team

Department of the Interior, Bureau of Mines, Denver Mining Research Center

U.S. Geological Survey, Oil Shale Supervisor's Office

Environmental Protection Agency

State Agencies

Colorado Division of Wildlife

Colorado Department of National Resources

Colorado Mined Land Reclamation

Universities

University of Colorado

University of Wisconsin

University of Montana

Texas A&M

Colorado State University

Consultants

ERT/Ecology Consultants, Inc.

NUS Corporation representing Rio Blanco Oil Shale Company

2.0 GENERAL PROBLEM AREAS

The panel found it very difficult to divide itself logically into subpanels. After an initial assessment of problem areas was made by the panel as a whole, two subgroups were formed, one to consider biological factors, and the other, physical and chemical factors. The broad problem areas then were grouped into the following categories:

- ecosystem dynamics
- baseline data
- mine dewatering and water quality
- subsidence and pit slope stability
- management, of raw and processed shale piles (waste shale management
- air pollution effects
- wildlife management

The group recognized that this division was not entirely logical and contained many overlapping areas. It is to be emphasized that the division was done primarily on practical grounds without any theoretical basis.

The panel identified 25 broad problem areas. Of these, 15 were considered to be high priority, 3 were considered to be medium priority, and 7 were considered to be low priority. This listing is not meant to be all-inclusive nor fixed in time. The criteria for the various priorities were not explicitly stated. Thus, at times, an area may have received a low priority because the group felt that such research was not needed or not possible in the immediate future. The priorities thus reflect only the consensus of the group at the present time.

The broad program areas by priority were:

High Priority

1. Spent shale disposal (including catalysts and other wastes)
2. Prediction of ambient levels of pollutants to which organisms are exposed. Current models are thought inadequate, and monitoring approaches are not predictive.
3. Impact on air quality of fugitive dust (particulate matter) from extractive and conversion processes. Particle size and chemical composition data are needed.
4. Subsidence of underground mines
5. More complete source characterization as a function of process variables (e.g., temperature) and resource variables
6. Effects of mine dewatering on receiving media for all oil shale mining techniques with respect to treatment and disposal
7. Effects of removal, storage, and replacement of (topsoil) overburden from open pit mining sites. (Stockpiled topsoils are left to weather.)
8. Methodological gaps exist in conducting or specifying baseline studies.
9. Develop mechanisms for collation and intensive review of all relevant data bases and measurement procedures
10. Improve design for biological baseline measurements and monitoring, considering local (near site) problems and those resulting from long distance transport of pollutants
11. Biological consequences of uptake of toxic elements by revegetation as expressed in plant and animal pathologies
12. Raw shale storage: leaching and runoff of chemical species, spontaneous combustion, resuspension of particulates, and ultimate disposal of extracted low-grade shale

13. Effects of NO_x emissions and enhanced oxidants on both local and remote vegetation

14. Direct effects of total projected regional gaseous and particulate emissions and induced oxidants

15. Indirect effects from interactions within ecosystems and related ecosystem level reponses (impacts on basic biological functions).

Medium Priority

1. Screening indigenous species for chronic as well as acute responses to identify particularly sensitive components in the biota

2. Stability of slopes in open pit mining operations

3. The introduction of nitrates into the groundwater through the extensive use of ammonium nitrate fuel oil (ANFO) explosives for modified in situ operations.

Low Priority

1. Assess potential consequences for the terrestrial biota of worst case of catastrophe situations--earthquake, drought, severe inversion persistence

2. Develop standard test organisms (plant and animal) for screening and evaluating chronic and acute responses to effluents

3. Dust from crushing and grinding and associated air quality impacts (probably controllable by current control technology)

4. Synergistic responses of organisms to the combination of NO_x, SO_2, and ozone in the oil shale region

5. Impact of construction, operation, corridor development, population increase, and noise on animal species, particularly large mammals

6. Effects of gaseous emissions and oxidants on small mammals, insects, and bird populations

7. Extent of differences between shale oil-derived products and conventional natural petroleum products. Extensive characterization is needed.

As previously stated, these problem areas were grouped into seven more or less broad categories for consideration in detail by the smaller groups of individuals. These smaller groups then considered these problem areas in more detail, attempting to define data requirements and specific research projects.

In most cases, the subpanels restated the problem areas. The amount of detailed description of projects varied with the area. The variation was partly due to the nature of the problem areas and partly due to the familiarity of the panel members with each area.

The subpanels were asked to provide brief overviews as well as problem and project statements. These overviews provide a succinct discussion of the principal issues and problem areas that were delineated by the groups. The accompanying research projects provide the subpanels' best judgments (in the time allotted) of the approaches needed to gather the information required to deal with these issues.

3.0 SUMMARY AND INTEGRATION OF NEEDS

Specific needs identified by the various subpanels are listed in Section 4. Perusal of these needs, which include a total of 44 rather loosely defined "research tasks" (Table 3-1), reveals some themes that recurred in several of the subpanel discussions.

TABLE 3-1. Research Tasks Identified by Seven Subpanels.

Subpanel	Number of Research Tasks
Ecosystem Dynamics	4
Baseline Information	4
Mine Dewatering	5
Subsidence and Pit Slope Stability	6
Raw and Waste Shale Management	12
Air Pollution Effects	9
Wildlife Effects	4
Total	44

The first of these is a need for some mechanism to compile, review, organize, and synthesize data from research already completed or currently underway on oil shale development. A second need mentioned by several subpanels was the necessity for interrelating the data, information, and research from a total-system view; i.e., integrating information from oil shale technology with information on air and water quality and ecology in a broad framework that considers the interactions within the entire environmental system.

Ecosystem processes, whether physical, chemical, or biological, were discussed by several subpanels. The need is to understand those processes better so that man can predict the transport patterns of environmental pollutants through the air, water, or biota.

A fourth subject mentioned frequently was mathematical models: geological, hydrological, air quality, and ecological. These are needed for better understanding and prediction of environmental impacts. A fifth area of concern was one of methodology. Many existing state-of-the-art methods simply are not good enough to answer the kinds of questions about oil shale development that need answering. The physical, chemical, and biological techniques for monitoring programs must be improved.

A final theme dealt with biological sensitivity to toxins associated with oil shale technology. This problem is two-fold: First, the toxic characteristics of oil shale pollutants must be better understood and, second, sensitivity of biota to these toxins needs to be much more clearly defined.

4.0 PROBLEM STATEMENTS, INFORMATION NEEDS, AND RESEARCH PROJECTS

4.1 Ecosystem Dynamics

An environmental system contains living things interacting with both the nonliving environment and each other. The system, therefore, should be viewed in its entirety, rather than as a collection of unrelated objects. Many ecologists believe that the system takes on unique emergent properties that are not predictable from an analysis of the ecosystem components separately. This holistic perspective also states that these emergent properties often cause the system to behave counterintuitively, i.e., to respond to perturbations in unforeseen ways.

Ecosystem components (the structural elements) change in space and over time as a result of ecosystem processes (the functional elements). These processes control the movement of matter and energy throughout the system. They therefore control the linkages between ecosystem components.

With the exception of obvious impacts such as bulldozing and erosion, most ecological effects of oil shale development will be subtle. Chronic and indirect effects on the ecosystem components are a result of complex interactions among those components through the processes that regulate the quantity and qualities of any ecosystem component. In most cases environmental perturbations caused by oil shale development will enter the biota from one or more transport media: air, water, or soil. The biota will be affected by these perturbations as a result of the biological processes that take up a pollutant and move it through the food web. We need to understand the key processes for specific major or dominant species on oil shale lands in order to predict impact and plan mitigation efforts. Such understanding would also help modify monitoring programs to be more meaningful.

4.1.1 Problem Statement

Many ecological studies in the past have concerned themselves with the time-dynamics of ecosystem components, i.e., how the quantities (and qualities) of these components change over time, without regard for cause and effect. Until recent years, very little was known about the pathways by which matter and energy flow throughout the system. Even less is known about the processes that govern flow rates in these pathways.

However, often by the time a perturbation to the ecosystem (a pollutant) is reflected in the gross, easily observable characteristics of the biota, the damage is widespread and extensive. If the time dynamics of the processes themselves were known and monitored, such damage could be averted or minimized by using the change in rate of an ecological process as an early warning of impending damage to the ecosystem component(s) affected by that process.

Ecological processes can be categorized as chemical, physical, and biological. Physical processes include such things as precipitation, erosion, and solar radiation. Chemical processes include photosynthesis and respiration. Biological processes are things like breeding, gestation, birth, nursing, etc.. An example (but in no way complete) list of ecological processes is provided below.

Example List of Ecosystem Processes

Abiotic

Solar radiation
Convection
Conduction
Precipitation
Evaporation
Melting
Freezing
Infiltration
Percolation
Runoff
Flooding
Groundwater flow

Biotic

Germination
Phenology
Nutrient uptake
Translocation
Photosynthesis
Respiration
Transpiration
Grazing
Plant shattering
Interception of
  precipitation
Decomposition
Natality
Mortality
Growth
Reproduction
Immigration
Emigration
Predation
Food Selection

Broadly stated, the problem is understanding key ecosystem processes from a holistic perspective in order (1) to determine the indirect effects resulting from interactions between ecosystem components and processes (i.e., basic biological functions) with each other and with environmental perturbations from oil shale development, and (2) to understand the overall functioning of the total environmental system. The required research should be designed to determine "normal" seasonal rates of key ecosystem processes and natural variations of these rates as functions of influential ecosystem components (state and driving variables).

4.1.2 Information Requirements

The information required to attack the problem can be subdivided into three broad categories:

1. Criteria for identifying "key" ecological processes, based on (1) importance to natural ecosystem function, (2) potential vulnerability to oil shale development, (3) observability, and (4) measurability
2. Actual identification of key processes
3. Biotic and abiotic factors that affect the temporal and spatial dynamics of each process

4.1.3 Research Projects

Research projects on this problem could be conducted on one or more ecosystem processes simultaneously (on one project) or concurrently (on more than one project). Mutual cooperation between investigators in this type of research is extremely important, particularly where studies complement one another. The following suggestions for research are a generic approach to identifying and studying key ecosystem processes.

4.1.3.1 Task 1. Establish criteria for identifying "key" ecosystem processes, based on the following questions:

1. What environmental perturbations from oil shale development are likely to affect ecological processes, and what is the range of possible levels for these perturbations? Rank them in order of potential severity.

2. What physical, chemical, and biological processes are relevant to ecosystem functioning? Organize them in a hierarchy of groupings by level of detail (e.g., the broad process of "growth" can include the more detailed processes of photosynthesis, respiration, translocation, and transpiration). For each process, determine the following:
3. How important is the process to natural ecosystem functioning?
4. How potentially vulnerable is the process to oil shale development technology?
5. How observable is the process, i.e., is it easily studied at the current state of the art?
6. How measurable is the process, i.e., can it be quantified by determining the rate of the process under different environmental conditions?

4.1.3.2 Task 2. Using criteria from Task 1, identify key processes. For each process:

1. Review the literature to determine what has been done to date on quantifying the rate of these processes and the environmental influences on them.
2. For what ecosystem components (e.g., species) has the process been studied?
3. In what geographical region was the process studied, or was it a laboratory study?

4. What environmental conditions were studied concurrently with the process, and how well are these environmental influences correlated with fluctuations in the process rate?

5. What relevance does the past research have for assessing oil shale technology impact on this process?

4.1.3.3 Task 3. Determine what abiotic and biotic factors affect the rate of each process and, to the extent possible, determine the physical, chemical, or biological mechanism behind that effect. For each process:

1. Use the scientific literature to construct a conceptual model of the process and all the factors affecting it.
2. Use the conceptual model to hypothesize a quantitative model of the process.

4.1.3.4 Task 4. Establish field and/or laboratory studies to measure and quantify the dynamics of each process as a function of related biotic and abiotic influences. For each process:

1. Use the conceptual model and equation (hypothesized quantitative model) to design experiments for testing hypotheses about the process.
2. Use statistical models (correlation and regression) to assess the relative importance of biotic and abiotic factors hypothesized to affect the rate of the process.
3. Design field/laboratory studies to test the hypotheses and quantify the interactions between influential biotic and abiotic components and the process being studied.

4.2 Baseline Information

The baseline and ecosystem panels concurred that a holistic overview of the ecosystem is necessary to evaluate problems. The lack of such an overview has resulted in much of the confusion, inadequacies, and difficulties associated with environmental impact assessments.

Discussion with the water quality panel reiterated and underscored the problems of comparability and applicability of baseline data. Although it would be ideal to be able to make broad-scale comparisons of data obtained from other impact assessments, ecosystem baseline studies must focus on the specific region, site, or system being investigated.

Attempts have been made, however, to come to grips with the central issues, and a recent reference[1] served as a focus for discussion. This discussion brought out the fact that many baseline studies have concentrated on inappropriate data gathering, often via a shotgun approach. What is needed is the identification and focus on critical components and processes. A major problem is that nonscientific considerations, such as legislative dictates or "cookbook" approaches, often determine what types of studies are conducted and how they are conducted. A good field biologist may have an intuitive feeling for what type of assessments are pertinent but communication of this type of knowledge is usually impossible. However, important personal observations that qualify or clarify baseline data are often omitted (but should not be) from environmental impact assessments. Two specific examples of the kinds of studies that may be more useful are the chemical work being performed by R. Klusman and the pinyon project health-growth parameters suggested by C.C. Gordon and presented under the air quality panel.

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[1] States, J.B., P.T. Haug, T.G. Shoemaker, L.W. Reed, and E.B. Reed. 1978. A systems approach to ecological baseline studies. Western Energy and Land Use Team, Office of Biological Services, U.S. Fish and Wildlife Service, 2625 Redwing Road, Fort Collins, Colorado 80521.

Specific relevant problem statements were not formulated, not because none exist but, conversely, because there are so many and because these may be the most significant and difficult to resolve. However, the panel seemed to agree with many of the ideas discussed under Ecosystem Dynamics (Section 4.1). Other examples that demonstrate considerable potential for guidance in terms of ongoing baseline studies are the coal-fired power plant projects in semi-arid areas.

4.2.1 Problem Statement

The scope of these problems should be restricted to oil shale development in the Western United States. Two broad problems associated with baseline studies are the need to:

1. Identify, compile, organize, and evaluate existing information and data bases
2. Identify technology gaps and develop methods for monitoring and predicting the environmental impacts of oil shale development

Within the first broad category (evaluating existing information) were the following subtasks:

- identify types of data availability (e.g., inventories, physiological information, population data)
- identify variability attributable to methods and techniques (e.g., modifications of procedures, equipment performance and modification, error and variability associated with the operator)
- characterize natural variability in the systems studied in such a way that post-impact changes can be detected

Within the second category (technology gaps) were the following subtasks:

- evaluate existing methodology (e.g., air quality measurements, biological sampling)
- design and validate better ecological baseline evaluation and monitoring methods, as appropriate

4.2.2 Information Requirements

The information requirements identified by the baseline subpanel center around both extracting useful data from existing information and improving methods for conducting future studies. Three broad categories of information are listed: environmental, technological, and methodological. These information requirements are elaborated in the next section.

4.2.3 Research Projects

As in Section 4.1, the research projects listed below as tasks are more general than specific. They could be appropriately applied to a wide variety of specific studies.

4.2.3.1 Task 1. Compile, organize, and evaluate existing information and data bases within the scope of oil shale development in the Western U.S. Intensively review and collate these data bases and the measurement procedures used to collect the data.

- Identify types of data available (e.g., inventory, physiological, etc.)
- Identify variability attributable to methods and techniques (e.g., modifications of procedures, equipment performance and modification, operator-error and/or variability)
- Identify intrinsic natural variability in systems studied.

4.2.3.2 Task 2. Identify methodological gaps that exist in designing or conducting baseline studies. Some examples of these gaps are:

- What chemicals and transport media need baseline studies, and at what geographic scale?
- Better sampling protocols need to be developed.
- How can the array of gathered data be organized and integrated for further comprehensive analysis?
- Solid baseline data on species populations, and their dynamics due to natural fluctuations, are required to assess net impacts of oil shale development.

4.2.3.3 Task 3. Improve the design for ecological baseline measurements. Consider both local and remote problems.

4.2.3.4 Task 4. Identify gaps in monitoring technology and develop improved methodologies for monitoring and predicting the environmental impacts of oil shale development. To identify gaps, the technology must be developed from the perspective of a holistic overview of the ecosystem in mind. Specific suggestions for research include:

- evaluating existing methodology (e.g., air quality measurements, biological sampling)
- designing and validating better ecological baseline and monitoring methods, as appropriate.

4.3 Mine Dewatering

Mining of oil shale in the West will disrupt or dissect underground aquifers in the oil shale production zones. Successful development of oil shale resources will, therefore, require the dewatering of the mining zone, both for the protection of workers and the successful extraction of shale oil or raw shale ore. This dewatering process can induce a number of changes which may vary somewhat depending upon the nature of the mining operation (open pit, in situ, etc.). The ultimate impacts of mine dewatering on a regional basis are not known, although a number of site specific studies are underway. Potential impacts to the terrestrial system include:

1. Changes in distribution or availability of surface water sources
2. Changes in vegetation distribution and composition as a result of changes in surface and subsurface water supply
3. Changes in wildlife use of areas related to availability of water and/or forage
4. Changes in aquatic food chain link to terrestrial system resulting from disruptions to aquatic systems (e.g., erosion, sedimentation), or creation of new aquatic habitat
5. Changes in microhabitat as a result of surface subsidence caused by removal of underground water.

Dewatering and water management will be subject to a number of legal restraints and site-specific limiting factors. The basic need identified is to characterize the regional impacts of several oil shale development dewatering operations.

One approach for assessing these impacts is to develop vegetation distribution, soils distribution, and wildlife use maps, as well as inventory data, that can be correlated with hydrology modeling and aquifer drawdown data to identify these changes and to predict future changes. The research development effort should be directed toward identifying basic interacting components and the design of an analysis system for relating effects of dewatering to terrestrial effects, if they are shown to exist.

4.3.1 Problem Statement

The basic problem is to determine the cumulative terrestrial effects of mine dewatering and surface disposal and/or reinjection (water management) related to oil shale development.

Within this broad context are considerations of water quality, water supply, land disturbance, water quantity, and impacts on aquatic and terrestrial ecosystems. The major importance of mine dewatering to terrestrial ecosystems is its potential effect on surface water quality and availability, related effects on vegetative dynamics (plant succession) as water resources change, and secondary effects on wildlife as habitat changes occur. Four major areas of concern are:

1. Impacts of dewatering and associated activities on surface water flow and quality
2. Surface disturbances related to construction of impoundments (reservoirs, ponds, dams, etc.)
3. Effects on the water table
4. Surface subsidence related to water removal.

4.3.2 Information Requirements

The information requirements related to the above four areas were summarized by the mine dewatering subpanel as follows:

4.3.2.1 Surface Water Flow and Quality. Specific information needs are:

- amount of increase or decrease in surface flows due to aquifer drawdowns
- locations and extent of affected areas
- amount of erosion or sedimentation caused by increased flows

- identification of critical wildlife habitat that will be affected by changes in flow or water quality
- definition of the extent of habitat affected by the process and the mechanisms by which the effects are brought about.

Specific data are required to:

- establish severity of impact on wildlife and on the habitat on which they depend
- determine if cumulative regional impacts impose a greater impact than impacts from individual developments
- define effects on aquatic food web
- describe completely and accurately the effects on sensitive wildlife and critical habitat that occur in areas potentially affected by dewatering
- delineate adequately habitat disturbance and vegetation succession on a regional basis.

4.3.2.2 Surface Disturbances from Impoundments. The information needed includes:

- quantity and quality of water stored
- areal extent of surface disturbance
- type of habitat disturbed during construction
- number of proposed reservoirs in region

To provide accurate assessments of these disturbances, data will be needed to:

- define potential use or impact on wildlife and to establish new aquatic food-web organisms
- define regional effects on wildlife caused by loss of habitat, such as changes in migratory patterns to utilize water resources
- identify types of wildlife affected by habitat removal
- assess cumulative affects of regional development.

4.3.2.3 Effects on the Water Table. Information required to assess effects of dewatering on the water table include:

- quantity and quality of water removed
- points where removal will occur (location and number of dewatering points in region)
- aquifer characteristics (level, depth, connection, etc.)
- surface and subsurface discharges

Specific data will be needed to:

- assess effects on surface water resources available for wildlife use and habitat, on erosion and sedimentation, and on the aquatic portion of food web
- define habitat affected, potential regional effects, and impacts on wildlife movements related to water supply
- understand interrelationships of factors described above
- assess relationship of habitat changes and vegetation succession in view of limitations available to water management in the region.

4.3.2.4 Surface Subsidence. General information needs include:

- geotechnical characteristics of the affected aquifers
- geological structural properties of overlying strata
- rate and amount of subsidence
- effects of subsidence on wildlife and wildlife habitat

Specific data are needed to:

- assess potential subsidence
- assess terrestrial effects (including changes in slope aspect, drainage patterns, microhabitat, etc.)
- assess importance of impact.

4.3.3 Research Projects

Four research projects were identified by the Mine Dewatering Subpanel to correspond generally to the four areas of concern listed above (Section 4.3.1).

4.3.3.1 Task 1. Determine the relationship between effects of changing water tables on vegetation distribution and composition as correlated with a hydrologic model of dewatering effects. Data should be obtained on vegetation extent and distribution (aerial mapping) and correlated with hydrologic mapping and ecological information on water requirements of various plant species involved. The object of the study(ies) should be to develop a technique by which hydrologic modeling data can be related to vegetation distribution, phytosociology, habitat modification, and animal use. Statistical techniques should be applied, if possible.

4.3.3.2 Task 2. Develop a regional vegetation and soils atlas, by use of aerial photography and ground reconnaissance techniques, that can be used in conjunction with disturbance inventory information to define habitat disturbance and related wildlife effects. Research data obtained will be used to define extent and type of habitats disturbed on a regional basis and to project potential changes in migratory patterns (e.g., mule deer and waterfowl).

4.3.3.3 Task 3. Evaluate the existing data base and assess groundwater resources affected by oil shale development from a regional perspective.

4.3.3.4 Task 4. Study geotechnical characteristics of oil shale strata as related to subsidence potential.

4.3.3.5 Task 5. Develop and refine hydrology models to predict effects of mine dewatering.

4.4 Subsidence and Pit-Slope Stability

Underground mining and/or extraction of oil shale/shale oil may cause downward movement of the strata overlying the mine or in situ operations. This phenomenon is called subsidence. Subsidence is the result of many interacting physical factors including the mining method or in situ extraction method employed, geological and geotechnical conditions at the mine site, and terrain factors. When subsidence occurs, it can result in major alterations to the overlying terrestrial and hydrologic environments.

Subsidence resulting from underground extraction of oil shale and pit-slope failures related to oil shale surface mining both have the potential for seriously affecting the terrestrial environment in the vicinity of oil shale/shale oil production operations. Subsidence could result from any or all of the following mining and extraction activities: underground mining of shale, combination mining, true in situ extraction of oil, and modified in situ extraction. Pit-slope instability could result from open-pit mining operations.

While the impact area may be relatively small for a particular operation, the cumulative effect could be large if major development of shale oil were to occur. The change to the terrestrial environment from either of these phenomena could be extreme, even to the point of total destruction of the existing environment in the immediate vicinity of the subsidence or slope failure. Such extreme modification of the terrestrial environment would have a major effect on all portions of the ecosystem in the vicinity of the affected areas. (The effects on the pre-development ecosystem may be, in part at least, alleviated by the fact that the subsidence or slope failure will occur in areas that have already been heavily impacted during mine development.) Subsidence could also have a major impact on the water table, surface drainage, and aquifers in the vicinity of the operation.

Although mine-induced surface subsidence has long been recognized as having a major impact, there is a scarcity of reliable data and information about this phenomenon. For example: What are the causes of subsidence? What are the effects of subsidence on the terrestrial environment? What measures cans be taken to reduce subsidence and mitigate its effects?

Some subsidence information is available from coal-mining operations in England and Europe. In the U.S., in recent years, attention has been directed to the problems of abandoned coal mines in Pennsylvania, Wyoming, and Colorado, where cave-ins have occurred with subsequent surface subsidence and damage. The Bureau of Mines has been instrumental in initiating large-scale backfilling efforts in Rock Springs, Wyoming, and in the anthracite region of Pennsylvania. Of course, these efforts are post-subsidence and are directed at correcting and/or reducing surface damage caused by subsidence.

The actual mechanics of subsidence have not been fully defined, and although considerable effort has been expended in developing theories and stress-analysis models, subsidence prediction is still in its infancy. Hence, most designs today are based on case history studies and subsidence monitoring to develop empirical relationships.

4.4.1 Problem Statement

Key problem areas are:

1. The potential for, and effects of, subsidence resulting from underground mining or extraction of oil shale on the terrestrial environment
2. Development of theoretical methods for predicting subsidence in oil shale formations

3. Development of methodology to select and measure critical geologic/geotechnical factors

4. Development of instrumentation systems to monitor surface subsidence.

Open-pit mine slope failures, if they occur, would completely destroy or alter the terrestrial environment in the immediate vicinity of the slope failure. A proven theory does not exist for the design of safe, stable, and economic open-pit mine slopes in oil shale. Improved pit-slope design would minimize the potential for slope failures and resulting destruction of the terrestrial environment.

While pit-slope failure is considered to be less critical for the purposes of this workshop, the key problem areas are essentially the same as for mine subsidence: namely, the effects of open-pit slope instability on the terrestrial environment.

The consensus of the committee was that subsidence is a high priority problem, and slope failure is a low/medium priority problem.

4.4.2 Information Requirements

The following information and other requirements were identified by the subpanel:

4.4.2.1 Subsidence.

- characterization of pre- and post-subsidence terrestrial environment overlying proposed underground or in situ oil shale mines in order to understand effects of subsidence on the terrestrial environment
- mining and/or in situ methods proposed for shale extraction at each site in order to evaluate subsidence potential

- geologic and geotechnical characteristics of material overlying mining/extraction horizon (fracture patterns, strength properties, stress conditions, mineralogy, depth of overburden) in order to evaluate subsidence potential and amount of subsidence to be expected

- methodology for evaluating and predicting the potential for subsidence resulting from a particular mining/extraction operation in order to study and monitor the subsidence process over time as extraction occurs

- instrumentation systems for monitoring and measuring subsidence as it occurs.

4.4.2.2 Pit-slope Failure.

- characterization of pre- and post-failure terrestrial environment in order to understand the effects of pit-slope failure on the terrestrial environment

- geologic and geotechnical characteristics of material in and overlying the mining horizon in order to assess the potential for pit slope failure and to design safe slopes in oil shale mines

- methodology for evaluating and predicting potential for slope failures in order to detect such events prior to failure

- instrumentation systems for monitoring slope stability and failure phenomena in order to describe the failure process as it develops with time.

4.4.3 Research Projects

Several broad research projects related to the above information requirements were identified by the subpanel:

4.4.3.1 Task 1. Determine the geological and geotechnical characteristics of materials overlying oil shale mining/extraction horizons, as related to subsidence.

4.4.3.2 Task 2. Develop methodology for evaluating and predicting subsidence caused by underground extraction of oil shale.

4.4.3.3 Task 3. Develop instrumentation systems for monitoring subsidence.

4.4.3.4 Task 4. Determine geological/geotechnical characteristics of shale deposits with respect to potential for pit-slope failure.

4.4.3.5 Task 5. Develop methodology for evaluating and predicting potential slope failure conditions.

4.4.3.6 Task 6. Develop instrumentation systems to detect potential slope failure.

4.5 Waste Shale Management

Oil shale, while constituting a large potential resource, is distinguished by the large amount of material that must be processed in order to obtain useful quantities of oil. A million-barrel-per-day industry will require the processing of approximately 480 million tons per year of oil shale. If processed above ground, approximately 1.2 million tons per day of processed shale will be disposed of on the surface. If the modified in situ retort method is used then approximately 250 thousand tons of raw shale will have to be brought to the surface and either deposited or retorted above ground, with the subsequent deposition of processed shale.

These quantities of raw and processed shale that will be either stored for long periods or permanently deposited on the surface are very large indeed; they are comparable (for a single oil shale plant) to the wastes associated with the largest mines in the world. The possible impact of the storage of raw shale on the surface has only recently become recognized as a major issue requiring research. On the other hand, some aspects of the management of processed shale have been studied for several years, but many critical issues remain to be resolved.

4.5.1 Problem Statement

The subpanel divided the problem into two large subproblems, which are:

- management of raw and processed shale: release, transport, fate, and effects of organic and inorganic substances associated with raw and processed shale
- management of raw and processed shale: stabilization, revegetation, and the storage of overburden from open pit mines.

4.5.1.1 Release, Transport, Fate, and Effects of Organic and Inorganic Substances Associated with Raw and Processed Shale.

Although a wide variety of technical and process options for extracting shale oil exist, certain unique features of oil shale technology distinguish it from other fossil fuel technologies in terms of environmental impact. Oil shale consists largely of mineral matter that increases in volume after removal of the oil. This greater volume must be disposed of. The processes with greatest commercial potential involve either complete above-ground retorting or retorting in situ after removing approximately 25 percent of the shale to establish sufficient volume for pyrolysis. Each of these actions involves return of processed shale to the environment.

Present plans call for disposing of wastes in the original mine and in local canyons. In addition, mine-run raw shale will be stored on the surface. The shale piles, which contain soluble inorganic and organic residues, must be stabilized against erosion, and it is likely that revegetation will be used largely for this purpose.

To assist in managing waste shale, there is a need to develop a basic knowledge of important processes influencing the form, mobility, chemical and microbiological stability, and plant and animal availability of the shale piles. This information must be developed and organized in a manner that will facilitate modeling mobility and biological availability over the long term. Pertinent information is needed on leaching chemicals to surface and groundwater, erosion and runoff from waste piles, resuspension of chemicals, plant uptake, animal intake, and possible remedial measures.

4.5.1.2 Stabilization, Revegetation, and Overburden Storage. There are several major problems associated with oil shale development as related to revegetation and stabilization of processed shale, overburden material, raw shale, and other surface disturbances. At the present time, there has been a minimum level of research done on the stabilization of Paraho, Tosco, and Union Oil processed shale materials. This work has been done on a small scale and has not addressed the question of long-term revegetation and stability. It is also important to realize that the physical and chemical properties of processed shale change drastically from one process to the next and within processes as temperatures and retorting modes are altered.

Virtually no research has been done on the revegetation and stabilization of overburden materials (from open pit mining) and raw shale (from modified in situ mining). This is an area of major concern since large quantities of both overburden and raw shale will have to be dealt with during the production of oil shale.

Surface disturbances associated with roads, pipeline, office, and retort facilities will be large in area but will not be as difficult to overcome in terms of revegetation and stabilization. Major research efforts in the future, therefore, should center around the physical and chemical properties of various processed shales, the use of this material as a plant growth medium (bioedaphic factors), and the effect on short and long-term plant community succession. If oil shale is mined with surface techniques, overburden must also be revegetated and stabilized for long periods of time. In addition, raw shale will have revegetation and stabilization problems different from those of either processed shale or overburden.

Besides problems associated with bioedaphic disruptions, the establishment of suitable biological communities in relation to diverse climates on a diverse topography must be studied. Questions of the degree of site specificity for plant communities and practices of establishing these communities must be resolved.

The final problem that needs research attention is disposal pile stability from an engineering point of view. Various disposal schemes have been proposed by oil companies directly involved in oil shale extraction technology. However, to date these disposal schemes and pile stability problems have not been tested on a large scale. Additional research and evaluation is needed on the engineering aspects of retorted shale disposal pile configuration, location, and stability. The research should address the problem of retorted shale compaction, slope stability, permeability, and other engineering criteria as they relate to both stability and successful revegetation.

4.5.2 Information Requirements

Two broad classes of information requirements were identified by the subpanel, based on the major subproblems mentioned above.

4.5.2.1 Release, Dispersion, and Effects of Chemicals from Oil Shale Piles. Certain factors govern the redistribution (transformations/effects) of potentially hazardous materials in processed shale and therefore relate directly to remedial measures and shale management. More data and other information are needed on these factors, a partial list of which follows:

- physicochemical characterization of processed shale, raw shale, and leachate as a function of resource, retort processes and shale management
- hydrologic profile
- microbiological/chemical transformation with time
- chemical composition of plants.

4.5.3 Research Projects

Specific research projects designed to tackle these problems are listed below as tasks.

Again, it is convenient to divide these into the two major groups as defined in 4.5.2, namely Release, Dispersion, and Effects of Chemicals from Oil Shale beginning with Task 1. and Stabilization, Revegetation, and Storage of Oil Shale Wastes beginning with Task 6.

4.5.3.1 Task 1. Determine detailed physical/chemical characterizations (particle size distribution, mineralogy, organic components) of solid phase and aqueous solubles (marosions, trace elements, polar organics, organic-metal complexes) as a function of shale source, retort temperature, and operation mode (heating/air mixture). Identify variables which might economically be altered to reduce mobility of residuals. This information should provide a broad (across-technology) basis for estimating potential problems related to movement and plant availability of residuals.

4.5.3.2 Task 2. Develop hydrologic balances (on a site-specific and required basis) to identify/quantify principal sources, avenues of movement, and repositories of precipitators, mine dewatering, and process waters relative to raw/processed shale piles. This information will be used in conjunction with information on shale solubles (initial status and changes with time) to predict mass movement of salts, trace elements, and organics to surface and ground waters.

4.5.3.3 Task 3. Identify principal biochemical (microbiological) and chemical (mineral weathering) processes influencing the composition/solubility of inorganic and organic residuals as a function of retort processes, pile location (aspect, elevation, configurations) and management practices. This information is essential to use of information provided in Task 1 above for prediction of long-term changes in mobility and toxicity of inorganic and organic residuals.

4.5.3.4 Task 4. Relate the inorganic and organic composition of plants to raw/processed shale properties. This program would take advantage of information collected in tasks 1 through 3 above to determine the accumulation of potentially toxic inorganic and organic residuals as a function of initial shale properties and changes with time (insoluble/plant-available components) which occur with different technologies, hydrologic profiles, and shale management.

4.5.3.5 Task 5. Evaluate the rates of uptake, transformation, and bioaccumulation of toxic substance by terrestrial organisms from both water, soil, and spent shale. Review existing information on the toxicity of substances identified by Task 1 (4.5.3.1). Perform multitiered biossays on concentrate and chemical fractions. Where additional information is required perform long-term laboratory animal tests.

4.5.3.6 Task 6. Evaluate the cementing characteristics of various retorted shale and the effect of cementation of disposal pile stability and water percolation. The project would assess the potential for retorting oil shale at sufficiently high temperature to calcify the material and thus make it improve through the leachings once the material is dumped into the disposal pile. Data required would be mode of operation of the retort, degree of cementation produced, and rate of infiltration and percolation of water through the material. This study would be both field and laboratory.

4.5.3.7 Task 7. Stabilize the vegetation on Tosco, Union Oil, Paraho and U.S. Bureau of Mines retorted shales. The project is directly related to the problem of surface stabilization of retorted shale disposal piles. The project addresses both the short-term revegetation problems and longer-term vegetative stabilization of the exposed surfaces of the pile. The project is a field study located in the oil shale area. The project should address problems of soil depth required, the effect of upward movement of salts, the erosion potential, and microbiological processes.

4.5.3.8 Task 8. Study ecotypic variation among plant species, plant species selection, and breeding to acquire plant species that will have superior fruits for stabilization and revegetation of retorted shale. Ecotypic studies with shrubs and forbs, and selection and breeding studies with grasses and forbs native to the Piceance Basin, should be carried out. Many species that have tremendous revegetation and stabilization potential need to be treated in these types of studies.

4.5.3.9 Task 9. Determine the effects of topsoil stockpiling on the plant growth potential of the material. How should topsoil be stockpiled and stabilized to maintain soil microorganisms at levels that will allow adequate plant growth when the material is replaced?

4.5.3.10 Task 10. Raw shale must be treated as a plant growth medium in a disposal pile, as is retorted shale. Research on both should include plant species adaptability, community succession, soil microorganism and mycorrhizal fungi activities, and fertility requirements for plant growth. Field test plots using raw shale should be established in a manner similar to that used for retorted shale to determine best methods for stabilizing and revegetating the material.

4.5.3.11 Task 11. Compare temperature at deposition rate of cooling, moisture content, and carbonaceous content of shale from various processes as they relate to possibility of thermal impacts and spontaneous combustion; assess near-surface temperatures in spent shale piles and thermal impacts on vegetation; assess possible mitigation of problems through pile design or alternative processes. Spontaneous combustion is clearly a threat to successful revegetation and possibly to pile stability over time.

4.5.3.12 Task 12. Determine criteria for locating disposal and construction sites in view of existing conditions, particularly slope, aspect, drainage, precipitation, elevation, etc. Three aspects to be considered are (1) potential success of revegetation; (2) engineering criteria for stability of the pile; and (3) how drainage should be routed around or through the pile. Existing drainage technology (i.e., rock drains, etc.) may not be applicable to spent or raw shale disposal due to the toxicity and/or leachability of the spent shale and resultant H_2O quality problems. Careful consideration must be given to the long-term stability of the landscapes of northwest

Colorado (To date the existing companies are proposing using standard mining and waste disposal techniques, ignoring potential leaching problems).

4.6 Air Pollution Effects on Plant-Animal Systems

Air pollutants, including various and unknown quantities of SO_2, NO_x, CO, HC, trace elements, radionuclides, trace organics, and other emissions that may be evolved from oil shale activities, seem likely to present high-risk problems for plants and animals. Which individual pollutants or combinations thereof are of greatest concern is speculation at best, a problem exacerbated by the presence of competing pollutants of unknown origin in the development areas.

Nevertheless, the potential for biological impact from direct, synergistic, and indirect pollutant effects seems real and therefore raises the need for intensive, holistic, and process-oriented approaches to ecosystem function before massive development proceeds. Such studies should screen sensitive biotic components in the laboratory and develop dose/effect relationships for both acute and chronic exposure at various levels and mixtures of effluent materials. Characteristic bird, mammal, and insect species at various trophic levels should serve as information sources about ecosystem function, together with studies of pinyon-juniper ecosystems. Air pollution is expected to alter various organism functions. For plants these alterations may produce needle necrosis, mottling, tip burn, and secondary invasion. In pest species, decreased growth and germination might be anticipated. For animals, effects may include behavioral avoidance and consequent species loss from the impacted area, decreased reproductive fitness, generally depressed animal health, and secondary complications owing to overstress and loss of resistance.

4.6.1 Problem Statement

Because of the anticipated growth and development of oil shale resources, consequent by-products of the oil shale industry need to be evaluated for toxicity in plant and animal systems. Sensitivity of biotic components to gaseous oil shale effluents is unknown and studies need to be initiated to identify those plants or animals whose loss will be first noticed in developed areas. These studies should include not only use of proven techniques for organism assessment but new physical and chemical methods suggested in new information of effluent chemistry and necessary refinements in current methodologies.

More specifically, the total output of various types of gaseous emissions appear to be sufficiently high to impose serious hazards to animal life. In particular, NO_x and PM discharge (17 & 7 tons/day), excluding radionuclides, from all phases of the energy cycle (especially retort operations) create certain high-risk problems for organisms exposed for months or longer. Upgrading operations and tail-gas cleanup also increase the atmospheric burden, especially of SO_2. In addition, trace element discharges, although not yet well characterized for oil shale operations, would appear to be rich in the volatile elements As, Hg, B, and perhaps Fl.

Boron and fluoride are both phytotoxic, Fl being more zootoxic than B. Mercury exudite has high bioaccumulation potential in animal systems. Toxicity of arsenic in both plant and animal systems (some insects excepted) is lower than any of the other trace elements. However, As probably is more volatile than Fl, Hg, or B and may preferentially be associated with aerodynamic small particles that have long atmospheric residence times. The importance of defining effective particulate sizes is therefore of obvious importance, since smaller particles penetrate deeper into the respiratory conduits of air breathers. Particle size is affected by humidity in hygroscopic particles, and toxicity of gases is affected by temperature. Trace organic components (e.g., PAN, poly-HC oxidized derivatives) which exhibit carcinogenic or teratogenic activity (e.g., BaP) may also exist in the volatile phase of retorting.

The impact of all these substances, individually or acting in concert or synergistically, can be imparted to animal systems by one or more of the following mechanisms: (1) inhalation; (2) ingestion in water or in plant/animal food; (3) surface penetration.

Effects may be elicited by direct stimulation of epithelial lining resulting in initiation of consequent immediate behavioral responses, or by internal interactions with cells of body fluid compartments, intracellular enzyme systems, or enzymatic cofactors. These latter interactions may generate system malfunction, aberrant behaviors, or pathologies manifested in unequivocal changes in life-table functions (mortality, survival, age at first breeding, etc.), progressive deterioration of species vitality, or loss of species.

Some of these effects, if due to metals, may occur over the entire lifespan, especially of longer lived species.

Other specific problems include the following:

- The effects of known phytotoxic gases, such as NO_x, SO_2, O_3, PAN, and Fl on the growth/health parameters of the two indigenous species of pinyon pine in the oil shale development region are not well understood.
- Toxic emissions may affect avian abundance or diversity, or may create mechanisms of increased avian mortality. Migratory birds are present six months or less and may carry toxic substances unrelated to oil shale mining operations, thus thwarting efforts to understand the role of species as accumulator or indicator.
- Toxic gaseous or particulate emissions may seriously affect resident small mammal populations by loss of species diversity, impairment of vigor, or decreased reproductive effort.
- Toxic substances in gaseous stream components of oil shale energy cycles may significantly alter population dynamics of terrestrial insects at locations both near and far from the source(s).

4.6.2 Information Requirements

4.6.2.1 Plants. The two species of pinyon pine found in Colorado, Utah, and Arizona where oil shale development is likely to occur are *Pinus edulis* and *P. quadrifolia*. Currently there is a great paucity of literature on the susceptibility of either of these species to any of the known phytotoxic gases, such as NO_x, SO_2, O_3, PAN, Fl^-, etc. However, as with other conifers, these two are dominant in the habitats where they grow.

The pinyon pine habitat consists of gravelly rocky soils, mesas, benches, and canyon walls at elevations of 5,000 to 9,000 ft.

Probably no other species of plant at these elevated semi-arid sites will constitute a better bioindicator of air pollution impacts. The reasons are:

1. Both maintain 4-5 years of foliage (needles) on their branches
2. The growth/health damage character can be quantified for these different aged foliage (1-to-16-month exposure periods) prior to and after the siting of stationary sources of air pollution
3. Both are found on the most elevated exposed ridges throughout the area and thus are openly exposed to emissions (plume strikes)
4. _P. edulis_ is an important food source (pine nuts) to the indigenous rodent population. These are also collected for human consumption. If trace elements are accumulated by pine foliage, some of these elements may become incorporated in the food chain of pinyon-juniper ecosystems.

Quantification and use of the growth/health damage of pine foliage for determining low, chronic air pollution trespass and impact have been reported by Gordon et al. (1977, 1978) and Tourangean et al. (1977). Low chronic levels of air pollutants in the ambient air cause an increase in needle pathologies such as tip necrosis, mottling, and necrosis of bases of needle tissues beneath the fasicular sheath. Both of the pinyon pines retain their fasicular sheaths for two years prior to shedding these deciduous tissues.

More specific information is needed on these pinyon pines as bioindicators of air pollution impacts.

4.6.2.2 _Plants and Mammals_. Some general information requirements that apply to both plants and animals are (1) that biotic components of oil shale basins should be screened for sensitivity to chronic and acute responses to oil shale effluents, and (2) test organisms should be identified for broad-based evaluation of toxic effluents.

4.6.2.3 Birds. More information is needed on birds in relation to air pollution, particularly as applies to breeding biology and phenology, basic physiology, and bioaccumulation.

4.6.2.4 Insects. Insect populations are known to be harmed by gaseous, particulate, and mist forms of zootoxins such as sulfur oxides, nitrous oxides, several trace elements, and acid mists. Population responses shown to occur include changes such as proliferation of phytophagous insects (probably due to predisposition of the host by pollution stress to attack, or to imbalances in predator-parasites caused by accumulations of toxic substances on the higher levels of trophic organization); decreased abundance of beneficial predatory and decomposing arthropods of soil/litter subsystems; and the uptake and magnification of concentrations of toxic substances through trophic levels or by accumulators, such as pollinators, which forage extensive areas.

Ecologically and economically, insects are known to form important components of terrestrial food chains and nutrient cycles which markedly influence the development and composition of plant communities, either through beneficial activities as pollinators and litter decomposers, or through "destructive" activities, such as severe grazing by herbivores. These activities may be more important than generally recognized.

For example, insects have been described as primary regulators of productivity and nutrient cycling in specific ecosystems; i.e., in forests. Pollinators contribute to the pollination of crops which directly or indirectly yield possibly as much as 1/3 of the total U.S. diet (S. E. McGregor, USDA Bee Pollination Research Lab, Tucson, Arizona.) Finally, entomological studies of the impacts of emissions from coal-fired power plants on insect populations of semi-arid regions have demonstrated detectable and significant impacts on entomological systems which are important to key ecosystem processes. Similar information is needed in relation to oil shale development.

4.6.3 Research Projects

Research projects designed to provide the kinds of required information identified above include:

4.6.3.1 Task 1. Review the existing literature regarding the effects of toxic substances identified in oil shale effluents on terrestrial organisms. Identify priority compounds and organisms requiring further research.

4.6.3.2 Task 2. Screen indigenous species of plants and animals for acute and especially chronic responses to various oil shale effluents (1) to identify particularly sensitive biotic components and (2) to select test organisms for broad-based evaluation of degradation of plant and animal resources.

4.6.3.3 Task 3. Review existing literature on characteristics of test organisms. Select test organisms on the basis of the following:

1. Wide distribution and high abundance
2. Small size (animals) to facilitate laboratory experimentation or ease of growing and maintenance (plants).
3. Short life span (e.g., 4 years or less--animals)
4. Exhibition of marginal adaptations. Rare and endangered species may be excepted because of obvious limitations.
5. Participation in various tropic levels; selection at different trophic levels.

4.6.3.4 Task 4. Initiate and maintain an ongoing review of available techniques on screening of animal and plant systems. Obtain dose/effect relationships for known toxic agents administered orally, parenterally, aerially, and topically. Obtain data on metabolism, growth, and reproductive susceptibility. Test these agents in concert for synergistic effects. Develop criteria for assessing chronic effects in living systems, paying special attention to alterations in immunological and neuro-endocrine variables (at various stages of the annual cycle) and the development of teratogenic and mutagenic anomalies.

4.6.3.5 Task 5. Analyze the effects of realistic, chronic, but variable NO_2 exposures on metabolism and growth of plants. Gross effects of NO_2 exposures are reasonably well documented (see N. Glass, 1977), but little is known about field effects of NO_2 variation and short-term exposures to high concentrations. A detailed experimental program comparable to that done for SO_2 over the past 10 years should be undertaken to obtain dose-response curves for major crop and native species in the shale oil area. Plants are relatively insensitive to NO emissions, and in any case the NO is rapidly converted to NO_2 by photochemical reactions.

4.6.3.6 Task 6. Assess the effects of mixtures of NO_x, SO_2, ozone, and peroxacyl nitrates on the principal plant species of the shale oil area. NO_x is a principal contributor to atmospheric reactions that form ozone and PAN in the presence of hydrocarbons. Ozone and PAN can have serious direct effects on plants, and ozone can bring about synergistic effects on some species when in the presence of relatively low levels of SO_2. Detailed experimental results and projections of rates for the oil shale region are required from air quality analysis and modeling. With these estimated inputs, and the results from experimental dose-response relationships for the principal plant species exposed to the mixtures of NO_x, SO_2, ozone and PAN, a projection can be made of local and remote (5-50 miles) effects.

In general, the biological effects of toxic gases, hydrocarbons, particulate emissions and their major interactions or synergism in animal populations should be investigated.

4.6.3.7 Task 7. Pollution sensitivity of birds will vary seasonally, with time of day, and with the presence of competing secondary stresses (e.g., disease, PCB load, other pollutants, intense competition). Studies must consider annual cycle components to account for natural variations in variables measured. They should include the following components, as well.

1. Review of existing literature relating birds and air pollution
2. Periodic censusing (for relative abundance and diversity indexes) for several seasons
3. Breeding biology and phenology: duration of maturing period, nest building, incubation and brooding, clutch size and number of clutches per season, nest mortality, times of year
4. Basic physiology: sampling birds as setting permits for body weight, molt stakes, level of obesity, and hematological observations: hematocrit, hemoglobin, plasma protein, leucocyte counts, effectiveness of immunological challenge
5. Periodic sampling for trace element and radionuclide assay in selected tissues (e.g., liver, spleen, kidney)
6. Select species at various trophic levels (e.g. granivores, carnivores), and continue monitoring for validation studies.

4.6.3.8 Task 8. Study small mammals with special attention to diurnal variation of various functions. Deer mouse and least chipmunk are suggested because these are mobile but nonmigratory, insectivorous and herbivorous, and they are abundant and easily captured. They are adaptable to laboratory studies as well. Components of this research should include the following:

1. Review pertinent literature
2. Emphasize nocturnal animals because of anticipated increased exposure at night owing to downslope air movement into canyon bottomlands
3. Conduct population density studies, especially on national population variability. Obtain data on seasonal changes in species numbers.
4. Collect (live-trap) specimens for basic physiological functions: body weight cycles; sex/age structure; hematology (hemoglobin, hematocrit, plasma protein, immunological competence; white blood cell counts and other growth/development data.

5. Data on reproductive cycle, litter size, number of litter per season, embryo development (size)

6. Tissue scans for trace element and radionuclide content

7. Data may be collected spatially so as to form an environmental gradient from a point source of pollution

8. Need to interact strongly with air-quality people and those concerned with water quality and quantity and revegetation. For example, water pollution may be instrumental in effecting population changes. Plants growing on reclaimed areas may accumulate B, Md, and other minerals in quantities sufficient to affect herbivores or herbivore predators.

9. Behaviorial data: shift of burrows or unusual behavior.

4.6.3.9 Task 9. The number of insect species exposed to oil shale development effluents would number in the hundreds to thousands. Species selected for study should be particularly important or crucial to key components and processes of impacted ecosystems, such as major herbivores, pollinators, decomposers, or predators-parasites of destructive (pest) insects. Unfocused data collection, such as extensive species lists and surveys, are costly and probably not of sufficient value to warrant inclusion. Types of data and information required include:

1. Review pertinent literature and species selection based on criteria such as sensitivity or susceptibility to harm, ecological importance, and economic importance

2. Characterize chemical components of concern, i.e., toxic materials

3. Determine the effects of chronic as well as acute exposures to the compounds in question. This includes both the effects of lethal and sublethal exposures on organismic and population characteristics.

4. Conduct baseline and post-operational characterization studies of dose/responses of insect populations as appropriate, such as:

   (a) Behavior (toxicant avoidance, disorientation, interference with host selection mechanisms)

   (b) Physiological (enzyme alterations, shifts in tissue compartmentalization, neurological, pathological, immunological)

   (c) Growth and development (teratologies, mutations, carcinogens)

   (d) Population functions (abundance, life table functions)

5. Bioassays for the uptake, accumulation, and transfer of contaminants through trophic pyramids of insects and higher organisms, such as mammals and birds, or for build-up in the systems of known accumulators, such as pollinators (Bromenshenk 1976, 1977, 1978)

6. Evaluation of the effects of alterations in insect populations on ecosystem resources which would, in turn, result in alterations of public service functions such as nutrient cycling, soil/litter decomposition, food webs, land reclamation, and possibly effects such as those suggested by B. Cornaby (Battelle, Ohio), who suggests that decomposer beetles (shown to be sensitive to air pollutants by Bromenshenk, 1977-78) may ameliorate, concentrate, or detoxify pollutants

4.7 Wildlife Effects

The problems relating to human activities in the corridor areas, and their effects on terrestrial fauna, are extremely complex. This not only involves human activities and structures specifically related to oil shale operations, but also to those activities incidental to industry production. Such human activities will certainly have a more profound effect on wildlife populations than all of the direct land use impacts combined. When it is realized that we are concerned with many species of terrestrial fauna, all affected differently by habitat, climatic, and human activity variables, the magnitude of the problem begins to register. Although we have tried to address the problems of human activities in the corridor areas completely independent of such things as vegetative changes, gaseous emissions, toxic uptake of plants, water flow changes, etc., there is really no way to completely divorce one from the other. The intense, detailed planning of specific research projects will depend upon the integration of all these variables.

4.7.1 Problem Statement

The human factor is believed to far outweigh surface disturbance and potential impacts of gaseous emissions on the terrestrial fauna of the Oil Shale Region. These effects will have both direct and indirect impacts on faunal groups.

The problem then is to determine the effect on faunal populations of human activity associated with construction and operation of oil shale plants including corridors. Subproblems identified are to determine the effects on: animal migration (i.e., mule deer); winter stress; summer stress; reproduction; mortality and interspecific competition (i.e., with livestock and feral horses).

4.7.2 Information Requirements

Human activity can be projected from development plans, etc. The effect on faunal characteristics and attributes will need to be studied concurrently with mining activities. More specifically, the following types of information are needed on human activities:

1. Type, number, location, and width of all corridors (i.e., roads, powerlines, rail lines, pipelines, water transportation systems)
2. Frequency of use of transportation corridors (general movement about the area)
3. Size and number of vehicles
4. Speed
5. Noise (operating equipment, blasting)
6. Gaseous emissions
7. Dust (particulate emissions)
8. Mitigation measures.

The first three types of information, and possibly the fourth, would be provided by development companies through mining and development plans and the Bureau of Land Management in cooperation with the State and County highway departments, utility companies, railroads and the Department of Transportation. Items 2 through 7 will require systematic monitoring to provide data sets. Item 8 will depend on the other 7 data items. Non-work related human activities should be assessed also. Examples of information requirements are:

1. Number of visits to area
2. Type of visit to area (camping, backpacking, etc.)
3. Poaching
4. Hunting pressure

Information on human activities will be needed from socioeconomic studies, wildland recreation studies, and both land and wildlife management agencies.

Information needed about fauna include:

1. Migration routes, locations, time of use
2. Winter stress--food, nutrition, cover, physiological condition
3. Summer stress--food, cover, space, condition
4. Reproduction--conception rates, birth rates (fecundity), abortion, young/adult ratios
5. Mortality--from disease and parasites, toxic elements, starvation, collisions and injuries, induced stress, weather (cold, heat, drought), poaching, hunting
6. Inter-specific competition

4.7.3 Research Projects

4.7.3.1 Task 1. Determine the effects of human work-related activities on avian fauna by censusing bird populations on and adjacent to development sites prior to development and periodically during project operation. This information is being collected on existing Federal lease tracts. Similar studies should be conducted on other development sites. Similar studies should be instigated at various points in the oil shale region to represent important habitat types from the subalpine to desert shrub locations.

4.7.3.2 Task 2. Determine the effect of human work-related activities on other faunal populations.

4.7.3.3 Task 3. Determine the effect of human non-work-related activities on faunal populations, e.g., winter stress effects on mule deer as exacerbated by human activity. Data will need to be obtained on deer condition in relation to winter activity of humans in the oil shale region. Animals will be captured and equipped with radio transmitters which record movements and such physiological functions as heart rate. Response to human intrusion will be monitored on a pre-arranged schedule.

4.7.3.4 Task 4. Determine the effects of human activity corridors on faunal populations, specifically on migration of deer and elk, through trapping and banding and/or radio tracking. Compare behavior to pre-development migration patterns.

AMBIENT MEASUREMENT AND MONITORING

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AMBIENT MEASUREMENT AND MONITORING

The success of many projects leading to the health and environmental assessments of oil shale technology depends upon the accuracy and the validity of information and methods which are used to measure and monitor the oil shale related energy activities. In order to investigate the shortcoming of the Ambient Measurement and Monitoring Program for oil shale technologies, and to recommend necessary research to improve the situation in a fashion most suitable to the energy development activities, the panel

1. Identified the critical needs in measurement and monitoring
2. Related each identified need to the appropriate phase in the oil shale fuel cycle
3. Made recommendations for necessary research in terms of problem definition, data need, and specific project descriptions

The panel deliberation resulted in the description of eleven projects which may be found in the body of this section. In what follows, a short description of the panels' findings and recommendations are summarized.

Summary

The preparation of synthetic fuels from oil shale requires several steps, each of which may result in the release of materials to the environment. These steps include mining, ore crushing, retorting, hydrotreating, and refining. During the retorting process a wide range of organic, metallo-organic, and inorganic products

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are volatilized. Some of these may be released to the environment within effluents, while others may escape as fugitive emissions. Pollutants may also enter the atmosphere as a result of subsequent hydrotreating and refining to produce final petroleum products.

The spectrum of compounds produced as a result of retorting of oil shale is considerably different than those found in normal crude petroleum. For example, shale oil contains much higher concentrations of nitrogen-containing compounds, PAH's, and phenols.

In assessing the potential environmental and health consequences of an oil shale industry, it is essential that reliable analytical methods be available for measuring potentially hazardous emissions both in products, effluents and wastes and in ambient air, water vegetation, biota, and soil. Classes of compounds which are of particular concern from an environmental and health effects standpoint include the PAH's, thiophenes, the N-heterocyclic compounds, aromatic and aliphatic amines, quinolines, furans, ketones, olefins, nitrates, light aromatics and various metals. Criteria pollutants including SO_2, NO_x, carbon monoxide and photochem oxidants are also of importance.

Because of the complex nature of products, effluents and wastes from an oil shale industry, it is necessary that reliable analytical techniques for the measurement of potential hazardous materials be evaluated.

In the area of analytical development, it is important that the suitability of the so-called standard analytical techniques be assessed. The complex nature of oil shale-process related materials causes serious interference in many conventional analytical techniques. The panel concluded that a considerable effort is required to determine the extent of resulting errors, to ensure the integrity of the methods, and to develop satisfactory modifications of these procedures to eliminate interferences. For example, presently many laboratories are performing analyses related to baseline measurement; these laboratories are using techniques that have been developed for other less complex matrices. It is essential that these methods be validated and, in some cases, adapted for oil shale related samples. It is particularly important that the validation efforts concentrate on the techniques which are available in the various commercial and government laboratories responsible for monitoring environmental samples. Such efforts are essential in the assessment of environmental and health effects and in monitoring environmental concentrations and accumulations.

The panel felt that it was impractical, at this time, to attempt to develop analytical methods for more than a small fraction of the total number of compounds generated in oil shale retorting and processing. Therefore, it was recommended that class separation techniques be developed to provide families of chemicals which can be used in toxicity and carcinogenicity testing. It was also recommended that specific analytical techniques be developed for those compounds which are known or suspected to be particularly hazardous.

Much of the analytical work performed on oil shale and its related products has been limited to trace cations. This is partially due to the speed and simplicity of multi-element techniques such as x-ray fluorescence, neutron activation, and emission spectrometry. Additional research is needed to develop similar multi-component techniques for anions. Techniques are needed which would permit complete characterization of process waters, leachates, etc., for polyatomic anions such as carbonate, sulfate, sulfite, nitrate, nitrite, etc. Better data on these trace constituents is important because they influence the solubility and mobility of both cations and anions in aqueous media. This information will improve the ability to study the bioavailability of trace species and to predict potential impacts on surface and ground water quality.

The panel concluded that an adequate understanding of bioavailability and toxicity requires the identification of the chemical form in which trace elements occur. In several cases the potential hazards of inorganic compounds depend on their chemical species which determine mobility, bioavailability, and toxicity. There are major differences in the potential hazard of an element depending on whether it exists as a free element, a salt, a methyl derivative, or a carbonyl. Inorganic compounds of mercury, arsenic, cadmium, selenium, molybdenum, iron, nickel, zinc, boron, fluoride, and chromium should receive particular attention.

An area which the panel felt should be emphasized in the near future is the development of rapid and continuous methods of analysis. This is particularly important for some of the airborne compounds such as PNA's, aromatic amines, nitrogen heterocyclic compounds, phenols, trace elements, and criteria pollutants. Real-time environmental analyses of these materials could permit correlation between plant operation, meteorology, and environmental and personnel exposure.

A major limitation in the analysis of concentrations and accumulations of pollutants in the environment is the ability to collect and store samples in a way which minimizes degradation. Better sampling methods are needed which will permit preconcentration of organics in water and air. Specific compound or compound class-selective adsorbents would simplify the sampling and analysis of complex multi-component mixtures. The key to significant advances in this area lies in improved separation technology. Several new gas and liquid chromatographic column materials need to be examined for their applicability to shale-related matrices. Additional research is also needed to develop selective detection systems to be coupled with gas and liquid chromatography. Detectors which could respond selectively to functional groups, compound classes, or specific compounds would simplify the qualitative analysis of these complex mixtures.

The archiving of samples is also important and will help meet several of the objectives of assessing the environmental influence of the oil shale industry. It is important that samples be collected and stored prior to the operation of pilot and demonstration plants so that pollutant concentrations in samples collected during or after the operations can be compared with those in baseline samples. It will then be possible to determine the influence of plant operation on a wide spectrum of potential environmental pollutants.

Finally the panel felt that characterization of organic constituents in oil shale, retorted shale, aqueous and gaseous by-products, is an extremely complex task. Current methodology is clearly inadequate to answer the essential environmental questions. Improved techniques are needed in several areas of trace organic analysis.

The analysis of oil shale and related materials has been plagued with serious analytical problems. The panel therefore recommends that serious attention be given to a quality control program that can ensure the reliability of analytical results. The area of quality control in analyses is also basic to all of the environmental and health studies and can help ensure a sound basis on which to assess the potential impact of a commercial oil shale industry.

QUALITY CONTROL FOR ANALYTICAL MEASUREMENTS ASSOCIATED WITH OIL SHALE RELATED MATERIALS

PROBLEM:

Quality control guidelines need to be developed and initiated among laboratories involved in analytical measurements associated with oil shale production. These guidelines should encompass both qualitative and quantitative aspects for organics, trace metals, and inorganics in all matrices. These guidelines should consider the controls to be applied, e.g., duplicates, blanks, comparison with reference materials, statements of precision, etc.

ENERGY FUEL CYCLE:

Quality control is required in all aspects of the energy fuel cycle where analytical measurements are necessary.

DISCUSSION OF NEED:

Quality control guidelines must be developed to ensure the quality (accuracy) of the analytical measurements associated with oil shale production. Guidelines should be established for both qualitative and quantitative aspects for trace metals, organics, and inorganics in all matrices. These guidelines should state such requirements as duplicates to be run, blanks, use of internal standards similar to the compounds of interest, and precision of the methods. In addition, laboratories should validate the accuracy of their analytical methods by regular analysis of reference standards such as the Standard Reference Materials (SRMs) of the National Bureau of

Standards. These reference standards should have matrices similar to the samples being analyzed. Reference Materials for certain trace metals in various matrices already exist. However, "Reference Materials" for trace metals in matrices more applicable to those associated with oil shale development need to be developed. At present, there is a great need for the development of reference materials or similar materials for trace-level organics in natural matrices. Such reference materials do not exist. As an interim measure, until the development of such standards, reference materials for use in interlaboratory comparisons should be made available to participating laboratories in the intercalibration study.

Many of the most abundant and toxic organic compounds associated with oil shale production are the alkyl-substituted polycyclic aromatic hydrocarbons and alkyl--substituted-N-heterocyclic compounds. Pure standards for most of these substances are commercially unavailable. The lack of such materials greatly hinders the positive identification of these compounds in the samples, and therefore reduces the value of the analytical data. The need exists for a program to synthesize such compounds and to make them available to the analytical laboratories. In addition, a number of such compounds labeled with carbon-14 would also be useful for use as internal standards.

EXPECTED MANPOWER:

Total Project	40 person years
Per year 1	10 person years
2	10 person years
3	10 person years
4	5 person years
5	5 person years

Total $ Resources over life of project: $3.0M

REFERENCE PROJECTS:

(30%) 1. Development of reference materials for trace metals in oil shale matrices

(50%) 2. Development of reference materials for organic compounds in oil shale matrices

(15%) 3. Synthesis of alkyl-substitutes PAH, N-heterocyclics and ^{14}C labeled analogs for yield determinations

(5%) 4. Development of quality control guidelines which are compatible with the complexity of the analyses.

DEVELOPMENT OF METHODS FOR THE DETERMINATION OF ANIONS IN OIL SHALE AND RELATED MATERIALS

PROBLEM:

A wide variety of methods is available for the analysis of inorganic anions. The problem here is that when a group of anions is to be determined, a variety of methods have to be used. In addition, some anions are serious interferences for other anions, (e.g., chloride and bromide, nitrate and nitrite, sulfate and sulfite). Anions containing arsenic, boron, fluorine, and selenium are found in fairly substantial amounts in shale and its products. In addition, nitrate and sulfate and mono- and dicarboxylic acids are present. Because of these difficulties and the presence of so many anions in shale products, there is a serious problem of excess cost and time in the measurement of the concentrations of a large group of anions whether they are present in air, water, waste, or in biological material.

ENERGY FUEL CYCLE:

These problems of analysis would be found in baseline measurements of shale areas, and in the analysis of spent shale, liquid waste from retorting, coke, and contaminated air, water, soil, and biological material.

DISCUSSION OF NEED:

What is needed are proven analytical method(s) that could determine these anions. The methods would have to be sensitive, highly selective, accurate, and capable of being automated. One potential method is ion chromatography. It separates the anions and then determines them by conductimetry. Anions, such as sulfate and sulfite, nitrate and nitrite, bromide, chloride, and iodide, arsenates and phosphates are readily separated and determined. However, the applicability and utility of this method in analyzing complex oil shale mixtures needs to be thoroughly assessed. Other potential methods utilizing derivation followed by GC or HPLC should be examined.

PRIORITY OF NEED:

Anions are important pollutants, and the priority for their measurement is high.

SEPARATIONS:

Research Projects

1. Investigation of the applicability of ion chromatography for the measurement of anions in oil shale-related liquids and extracts
2. New methods for selective analysis of anions.

ELAPSED TIME OF PROJECT (Initiation to Completion):

It is anticipated that each of the two projects would be conducted over a three-year period with approximately equal funding.

EXPECTED MANPOWER:

Total Project	10 person years
Per year 1	4 person years
2	3 person years
3	3 person years

Total $ Resources over life of Project: $800K

NEED FOR RESEARCH ON IMPROVED SEPARATION METHODS

PROBLEM:

Environmental samples associated with oil shale mining, retorting, and refining are extremely complex mixtures of compounds. This complexity makes oil shale-related samples more difficult to separate and analyze then most other types of samples. Better class separation methods and methods for individual compound separations are needed. The compounds vary greatly in toxicity, carcinogenicity, reactivity, persistence, and potential for photochemical smog generation; consequently, it is essential that the identities and concentrations of individual organic and metallo-organic compounds be determined in a variety of matrices.

ENERGY FUEL CYCLE:

Baseline measurements, mining, retort operations (ex situ and modified in situ), upgrading and refining.

DISCUSSION OF NEED:

Improved separation methods are needed before an adequate job of ambient monitoring and measurement can be done. Measurements made previously of such parameters as "total non-methane hydrocarbons" are inadequate in assessing potential health effects and photochemical pollutant potential. Information about the identity and concentrations of individual compounds can only be obtained if better separation methods are developed, particularly for the polar and more reactive compounds. Research is needed on high resolution gas and liquid chromatography columns, new polymeric-packed column materials, new selective and sensitive detectors, and related fields. Research is also needed on precolumn compound class separation materials. Many mixtures from oil shale samples cannot be adequately separated, even with the very best high resolution glass capillary columns now available. If effective, subtractor precolumns can be devised, certain compound classes could be removed while others are allowed to pass into the analytical column, in which the separation of the simpler mixture would be more nearly complete. Much research needs to be done on selective sorbents that will reversibly sorb and desorb specific classes of compounds.

PRIORITY OF NEED:

This is clear[illegible] of the highest priority needs. Without better separation methods all of the analytical methods are not as powerful and effective as they should be.

ELAPSED TIME OF PROJECT (Initiation to completion):

While we anticipate major accomplishments in the first five years, this is likely to be a long-term project in which steady progress will be made. As an illustration, gas-liquid chromatography was discovered in 1952 and has undergone continual development and improvement until today there are gas chromatographs in virtually every laboratory. It is difficult to predict how long it will take to discover new separation methods that will have an impact in the 1980's equivalent to that which has been made by partition chromatography in the past 20 years.

EXPECTED MANPOWER:

Total Project	50 person years
Per year 1	10 person years
2	10 person years
3	10 person years
4	10 person years
5	10 person years

Total $ Resources over life of project: $350K

ORGANIC ANALYTICAL METHODS FOR OIL SHALE-RELATED MATERIALS

PROBLEM:

There are a vast number of organic compounds, some of which occur naturally, to be found during ambient monitoring around shale oil production sites. Many of these compounds are present as gases, adsorbed on particles or dissolved in water. Current analytical methods for organic compounds have focused on relatively volatile nonpolar types of compounds. There are numerous other classes of compounds which need attention. For example, polar compounds which occur in ground waters and in retort or process waters are important because of their potential biological significance. Analyses based on classes of compounds will gain importance as possible parameters in ambient measuring and monitoring, but presently no really suitable methods exist.

ENERGY FUEL CYCLE:

Analysis of organic compounds in water, air, perhaps soil or biological tissues are important in baseline monitoring. As the shale oil industry grows, organic analyses will be necessary during mining, retorting, and upgrading, when the escape of compounds is most likely. During refining and use a comparison of petroleum- and shale oil-based products should be carried out.

DISCUSSION OF NEED:

Methods of analysis of organic compounds that are broad spectrum and can differentiate classes need to be developed. Improvements in gas chromatography such as capillar column chromatography with selective precolumns may improve analysis of nonpolar components. Novel derivation techniques could simplify gas chromatographic determination of polar compounds such as phenols, acids, or amines. The determination of polar water-soluble compounds has renewed importance in water analysis and new developments in high performance liquid chromatography (HPLC) appear to make these fruitful research areas. Undoubtedly, as research progresses, new compound classes will be found which may require novel detectors. Improvements in detector sensitivities including mass spectrometry are needed, since concentration of trace organics at the ppt ($1:10^{12}$) range may be important.

PRIORITY OF NEED:

Broad class analysis	high
Polar compound analysis	high

ELAPSED TIME OF PROJECT (Initiation to Completion):

Significant progress could be made in broad class analysis in two years. Polar compound analysis would require at least five years because new classes will be determined. Search for new detectors and increased sensitivity are very long-term projects.

EXPECTED MANPOWER:

Total Project		25 person years
Per Year	1	5 person years
	2	5 person years
	3	5 person years
	4	5 person years
	5	5 person years

Total $ Resources over life of project: $1.75M

RESEARCH PROJECTS:

1. Analytical methods for highly polar organic compounds
2. Development of class separation of organic compounds
3. Improved analytical methods based on derivation

SEPARATIONS:

Research Projects

(35%) 1. Chromatographic separation of nonvolatile compounds in shale oil and spent shale leachates

(35%) 2. Application of High Resolution Gas Chromatography to Shale Oil-Related Compounds

(10%) 3. Development of Selective Subtractor Precolumn Methods for Gas Chromatography and Liquid Chromatography

(10%) 4. Porous Polymers or similar materials which permit reversible sorption of compounds for preconcentration or use as Chromatographic Media

(10%) 5. Separation techniques for inorganics in difficult matrices.

DEVELOPMENT OF METHODS FOR TRACE ELEMENT SPECIATION MEASUREMENTS

PROBLEM:

The mobility, bioavailability, and toxicity of trace metals all depend on the chemical form in which they occur. For example, methylated forms of mercury are many times more toxic than inorganic forms. Except for a few cases, methods are not generally available at present to determine the chemical forms of trace elements in complex oil shale matrices and in environmental samples. Therefore, research is needed to develop such methods on a timely basis.

ENERGY FUEL CYCLE:

Speciation measurements are particularly important for the baseline, retorting, upgrading, and refinery phases of oil shale production and in determining the potential impact on human health.

DISCUSSION OF NEED:

Because the mobility, bioavailability, and toxicity of trace elements are all controlled by their chemical form, these forms or species must be determined in air, water, oil, spent shale, soil, plant, and animal samples connected with an oil shale development. For example, methylated forms of mercury are more toxic than inorganic forms, whereas the reverse is true for arsenic. As another example, if molybdenum is present as is the sulfide, it may be unavailable for plant uptake. Such considerations are particularly important for the oil shale industry because of the relatively high concentration of a number of potentially toxic trace elements and because of the presence of certain organic compounds which may complex the metals and thus change their properties. Elements of particular interest include mercury, arsenic, cadmium, selenium, molybdenum, fluorine (as fluoride), nickel, manganese, chromium, and possibly thallium. Although some work has been done with mercury and arsenic speciation and work is underway on such metals as zinc, mercury, cadmium, and selenium, this is an area which needs very thorough study. Possible analytical approaches include selective absorption traps, gas chromatography/mass spectroscopy, liquid chromatography/mass spectroscopy, and the coupling of both liquid and gas chromatographs with sensitive and specific inorganic detection methods, such as DC and microwave-coupled plasma emission spectroscopy, advanced atomic absorption spectrophotometry, or X-ray fluorescence and chemiluminescence.

PRIORITY OF NEED:

High

EXPECTED MANPOWER:

Total Project		30 person years
Per Year	1	6 person years
	2	6 person years
	3	6 person years
	4	6 person years
	5	6 person years

Total $ Resources over life of project: $2.0M

RESEARCH PROJECTS:

1. Method for determining the chemical species of potentially toxic elements in oil shale-related materials.

   Subprojects:

   a. Measurement of chemical species in gaseous emissions and air
   b. Measurement of chemical species in soil and ground water
   c. Measurement of chemical species in vegetation and biota
   d. Measurement of chemical species in shale oil
   e. Measurement of chemical species in spent shale and leachates and process water

ARCHIVING OF ENVIRONMENTAL AND PROCESS SAMPLES

PROBLEM:

Because of the low levels of organic compounds and trace metals anticipated in baseline studies, analytical methods may not have adequate sensitivity at the time baseline values are determined. Therefore, samples of water, soil, tissue, and biota should be collected and archived for comparison with values determined at a future date which may utilize more sensitive and more accurate methods. Similarly, analytical methods are not immediately available for analysis of product effluencesand water from retorting, and these samples should be archived both for this purpose and to provide representative material for environmental and biological studies.

ENERGY FUEL CYCLE:

Archiving of ambient environmental and process samples is especially important for samples collected for baseline and processing.

DISCUSSION OF NEED:

Current analytical methods for trace organics and trace metals often do not possess sufficient sensitivity to measure the low levels of these substances anticipated in a pristine environment. As a result, baseline data may have very little meaning. To avoid the loss of meaningful baseline information until the analytical methods achieve the necessary sensitivities, important baseline samples should be archived for future analyses. In addition to these baseline samples, samples collected at selected intervals should also be archived for comparison with baseline samples. Archiving of oil shale process-related samples is important to provide material for more accurate analysis. This will permit health and environmental studies on well-characterized materials. As a prerequisite to such sample archiving, the problems associated with preserving the integrity (i.e., component loss, alteration, degradation, etc.), particularly for samples to be analyzed for trace-level organic constituents, need to be studied.

PRIORITY OF NEED:

The archiving of baseline environmental samples must be given high priority because these samples can only be obtained prior to the production of oil shale. The archiving of process materials is also of high priority because of the importance of their future availability for more detailed analysis and biological studies.

EXPECTED MANPOWER:

Total Project		15 person years
Per year	1	4 person years
	2	4 person years
	3	3 person years
	4	2 person years
	5	2 person years

Cost $1.3M

RESEARCH PROJECTS:

1. Archiving of environmental samples
2. Archiving of oil shale process samples
3. Studies of stability of inorganic compounds during storage
4. Studies of stability of organic compounds during storage.

IMPROVED SAMPLING METHODS

PROBLEM:

There is a need for improved sampling techniques which ensure that the environmental and oil shale process samples are representative and that their integrity is maintained. Sampling often requires concentration of trace materials from large volumes and protection from degradation, loss, and contamination.

ENERGY FUEL CYCLE:

Reliable sampling techniques are essential to all stages of the fuel cycle.

DISCUSSION OF NEED:

Better sampling methods are needed for organic gases, vapors, volatile trace metals, atmospheric particulates (fine and coarse). Better concentration methods are needed for water-soluble polar organic compounds. Research is needed to selectively collect and concentrate inorganic and organic vapors, families of compounds such as olefins, benzenes, alkanes, aromatic amines, aza-arenes, ketones, furans, aromatics, and criterial pollutants such as nonmethane hydrocarbons, sulfur dioxide, and carbon monoxide.

PRIORITY OF NEED:

We consider all of these of high priority.

ELAPSED TIME OF PROJECT (Initiation to Completion):

Five years - we anticipate that the funding would be divided approximately equally between the six projects.

EXPECTED MANPOWER	Total Project	50 person years
	Per year 1	10 person years
	2	10 person years
	3	10 person years
	4	10 person years
	5	10 person years

Total $ Resources over life of project $3.8 million (1978 dollars)

RESEARCH PROGRAMS:

1. Develop reliable methods for sampling and preservation of organic vapors and gases
2. Develop reliable methods for collection and preservation of volatile trace element species
3. Develop methods for collection of aerosol which minimizes sample degradation
4. Develop methods for concentrating trace, substances from spurious media for analysis and biotesting
5. Develop methods for collection of specific classes of trace constituents from aqueous media.

ASSESSMENT OF WIDELY USED ANALYTICAL TECHNIQUE FOR APPLICABILITY TO OIL SHALE-RELATED MATERIALS

PROBLEM:

The unique chemical characteristics of oil shale and derived products and water lead to serious inteferences when some conventional analytical methods are used. This problem has led to errors in existing baseline and process material analyses. These errors could lead to serious implications in many phases of the oil shale industry.

ENERGY FUEL CYCLE:

Applicable to all phases of the fuel cycle.

DISCUSSION OF NEED:

Support should be provided for a systematic examination of the applicability of the widely used conventional analytical methods to complex oil shale matrices (conventional methods in this case mean methods currently mandated by law or widely used in other types of sample matrices). The following sample types represent matrices which are particularly difficult to analyze: raw and spent shale, leachates, and process waters. While there are useful and sensitive methods which require sophisticated instrumentation, these techniques are costly and unavailable for use in the many laboratories responsible for analyzing the large numbers of samples generated by baseline and process monitoring. Direct application or modification, if necessary, of some existing methodologies could be a cost-effective approach to providing reliable analytical methods.

PRIORITY OF NEED:

High

ELAPSED TIME OF PROJECT (Initiation to completion):

While we feel that considerable progress could be made in two or three years, we recommend this as a continuing project.

EXPECTED MANPOWER:

Total Project 15 person years

Total $ Resources over life of project: $1.1M

RESEARCH PROGRAMS:

1. Determine the suitability of conventional sample preparation techniques for total elemental analysis

2. Study the applicability of standard analytical technique, including GC, AA, electrochmical ion selective electrodes, and spectrophotometry to the analyses of oil shale-related matrices.

RAPID AND CONTINUOUS MEASUREMENT OF POLLUTANTS

PROBLEM:

There is a pressing need for the rapid and real-time measurement of the potentially hazardous pollutants associated with the oil shale fuel cycle. These measurements are particularly important for trace organics such as PNAs, aromatic amines, phenols, some of the volatile trace elements, and certain criteria pollutants. In assessing the potential health and environmental exposures associated with the fuel cycle, it is important to monitor actual levels in the ambient atmosphere in effluents and in working locations. Rapid analyses are also of major importance in collecting sufficient and reliable environmental baseline information.

ENERGY FUEL CYCLE:

Rapid or real-time measurements are important in all phases of the fuel cycle and are particularly important in the retorting, upgrading, and refining of shale oil where large personnel or environmental exposure could occur. Reliable methods for baseline monitoring are also of major importance. The pollutants released during various phases of the mining operation, including blasting and precrushing, are important.

DISCUSSION OF NEED:

The insult to individuals and the environs depends on the types of pollutants and the exposure rates. Real-time or rapid analyses can permit a correlation of plant-operating conditions and meteorological variables with exposure of plant personnel, the nearby populations, and the environment itself. The exposure of individuals and the environs to trace organics such as amines, phenols, nitrites, furans, caboxylic acids, criteria pollutants, volatile metals, and other materials must be estimated from ambient measurements. In order to obtain a sufficient amount of reliable information on exposure levels in a reasonable time, it is important that rapid or real-time analytical methods of sufficient sensitivity be developed. These developments should supplement and eventually replace many of the laboratory methods and should remove much of the uncertainty associated with sample collection. These developments should also lead to practical personnel dosimeters.

PRIORITY OF NEED:

High priority project

ELAPSED TIME OF PROJECT (Initiation to completion):

It is recommended that this program be conducted in two phases. In the first phase, developments should be initiated which could likely produce a useful rapid or real-time analysis method, together with those which are needed for assessing exposure to the more harmful pollutants. The second phase would include development of methods for as many of the more serious pollutants as practical.

EXPECTED MANPOWER:

Total Project		41 person years
Per year	1	5 person years
	2	7 person years
	3	9 person years
	4	10 person years
	5	10 person years

Total $ Resources over life of project $3M

RESEARCH PROJECTS:

Rapid or real-time analyses for:

(15%) 1. PNAs in the atmosphere

(15%) 2. Heterocyclic compounds in the atmoshphere

(15%) 3. Water-soluble polar organic compounds in water

(15%) 4. Trace element chemical species in air and water

(25%) 5. Criteria pollutants at ambient levels

(15%) 6. Personnel and working location dosimetry.

IMPROVED DETECTION SYSTEMS FOR ANALYSIS OF TRACE ORGANICS IN OIL SHALE-RELATED MATERIALS

PROBLEM:

Because of the complexity and diversity of organic compounds in shale oil-related materials and environmental samples, the analysis of trace organic materials is a difficult analytical problem. Development of improved or novel selective detection techniques could greatly increase the analytical capabilities for determining organic compounds in these complex matrices. In addition to being present in complex matrices, many of the compounds occur in low concentrations beyond the sensitivity of current techniques and therefore require a preconcentration step. Most of the current chromatographic detection methods do not permit specific compound identification, so more selective or specific detectors would greatly aid in qualitative as well as quantitative analysis.

ENERGY FUEL CYCLE:

Analysis for organic compounds is important in baseline monitoring, retorting, upgrading, and refining. Improved detection systems will aid in all these areas of the energy fuel cycle.

DISCUSSION OF NEED:

Perhaps the greatest needs in this area are detection systems which permit specific compound identification. Developments in detection systems for high performance liquid chromatography which provide qualitative information as in gas chromatography/mass spectrometry should be encouraged to realize these objectives. Better LC/MS intefaces need to be developed. Detection techniques for more sensitive determination of organic compounds are needed. Improved electrochemical methods, membrane electrodes, time-gated fluorescence techniques may improve sensitivity as well as selectivity. There are good possibilities for development of specific detectors which are relatively interference-free. The above approaches represent some of the possibilities for developing specific detectors which are interference-free.

ELAPSED TIME OF PROJECT (Initiation to completion):

The development of detection systems needs continuing support for at least five years.

MANPOWER REQUIREMENTS:

25 Person years

RESEARCH PROJECTS:

(30%) 1. Develpment of LC/MS

(15%) 2. Specific electrochemical LC detectors

(15%) 3. Nitrogen and sulfur LC detectors

(15%) 4. Develop selective reaction detection for use in liquid chromatography

(25%) 5. Develop additional GC detectors.

SOURCE CHARACTERIZATION

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OIL SHALE TECHNOLOGY SOURCE CHARACTERIZATION PANEL

Adequate characterization of an energy technology is a prerequisite to identifying its potential environmental, health and safety impacts. Such accurate definition and analysis is essential to the adequate planning and implementation of research to determine that the technology is acceptable from environmental, health, and safety standpoints.

Within this context The Oil Shale Technology Source Characterization Panel sought to accomplish two objectives: (1) to select those output streams of currently viable oil shale technologies which may present environmental, health or safety hazards; and (2) to identify those aspects of these processes which must be defined further in order to determine any need for additional environmental research.

To accomplish these two objectives, panel members divided their time between attending the other workshop panels, to provide technology and characterization expertise; and working as a group to identify areas where additional characterization research is required. Their input to the other panels has been incorporated into those respective panel reports., The conclusions and concerns of the Characterization Panel as a whole are presented in the present panel report.

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The characterization of oil shale industry technology as a prelude to identifying potential environmental, health, and safety impacts poses one simple problem. Source characterization data are adequate for engineering design, but not from health studies. This discrepancy is the basis for the often-encountered apparent anomaly between assertions that the characterization of most major oil shale process "outputs" has also been done, and the fact that further research in "steam" analysis and identification is still necessary, i.e., that characterization problems still exist.

Data accessibility may be limited because the data are proprietary, or perhaps because the dissemination systems are inadequate. Obtaining proprietary data usually will involve legal and economic constraints, while improving data dissemination will require establishing more elaborate data management and control. Obtaining adequate data appropriate for health effects and related evaluations requires interaction among the various users of such data during the planning and implementation of characterization research. This was a primary purpose of the present Oil Shale Workshop.

A second major factor to bear in mind in evaluating source characterization needs is that most data are necessarily site and process specific; and hence often vary as a function of operating conditions.

The suitability of such data must, therefore, be evaluated before the data can be properly used.

Another factor to be considered in source characterization is that the various oil shale processes are at different stages in their technical evaluation. This is particularly important because both the availability and requirement for data in designing and implementing environmental, health, and safety research depend upon the status of technical development.

It was the general consensus of the panel that technological source characterization of existing (experimental and demonstration) oil shale facilities has reached the point of diminishing returns. Extrapolation of much of the now-obtainable data to commercial size operations may not be either appropriate or meaningful. The Panel argued that larger scale facilities, e.g., commercial-size modules, would provide a comparison with the previously collected data on smaller plants, and might identify potential problems, not evident in the smaller-sized operations. Alternatively, some potential problems may disappear with scale-up.

A closely related question considered by the Panel is "what type of source characterization is needed?" If a given oil shale process is designed to be an essentially closed system, is it necessary to characterize all chemical species and/or classes of every process "stream" involved, even though the probability of release of most of these "streams" is minimal? Or is it sufficient, instead to characterize only those emissions, effluents and wastes to which the environment is likely to be exposed, either routinely or as a result of accidents or upset conditions?

This matter of hazard, which embraces the assessment of both toxicity and potential exposure, is crucial to proper design and implementation of an environmental, health, and safety program. No system can be made completely safe; all systems and industrial activities pose some hazards. The crucial judgment in technology source characterization is to identify the level of detail to which the characterization must be carried. While complete characterization of all source terms might be useful, the costs might be prohibitive.

After discussing the above considerations and questions at some length, the panel then briefly evaluated the various current major oil shale technologies and concluded that source characterization research is needed in several areas, viz.:

- solid wastes disposal, including spend shale raw shale, catalysts and chemical sludges
- treated process emissions and effluents streams
- potential surface and groundwater contaminants
- trace elements in all process streams
- air contaminants as occupational hazards
- nitrogen oxide emissions in process streams and from products use
- physical hazards in oil shale mining.

Problem Statement - Solid Waste Disposal

An oil shale industry will produce significant quantities of solid waste, including spent shale, raw shale, catalysts, and chemical sludges. Each type of solid waste could degrade air, water or the land. Procedures for adequately treating and/or disposing of solid wastes must therefore be developed and demonstrated if an oil shale industry is to be created. Disposal by backfilling mines or in situ retorts should be considered.

Data/Information Requirements -

Solid wastes should be characterized as a function of site and process. The potential for degrading air, water and land should be determined. Alternative methods for treating and/or disposing of each type of solid waste should be evaluated.

Required Research -

Permeability studies, leachate characterization and waste disposal management techniques should be conducted for each of the five major classes of solid waste: surface retorted shales; in situ retorted shales; raw shale; catalysts; and chemical sludges. Research should be process and site specific. Large scale operations are needed to provide adequate quantities of solid waste to demonstrate waste management. Both above ground disposal and backfilling mines and in situ reports should be evaluated. Criteria for post-operations disposal management should be established.

Priority - High

Problem Statement - Water pollution from shale mines and in situ retorts

Both active and abandoned shale mines and in situ retorts may contaminate surface waters and groundwaters. Potential problems appear to be site- and process-specific.

Data/Information Requirements

Some characterization work has been accomplished and may provide sufficient data to develop preliminary control plans. More baseline data on the water quality of aquifers must be collected. Effects of mining on water quality must be determined. Leachate from spent shale in in situ retorts should be characterized. The effects of cementation in in situ retorts and of sealing retorts should be evaluated.

Required Research -

Conduct laboratory study of leaching spent shales, using representative groundwaters. Mines and in situ retort operations should be monitored, and control technologies developed.

Priority - High

Problem Statement - Characterization of air emissions from various oil shale technologies

Air emissions have not been completely characterized for the various oil shale technologies. While practically all processing steps may produce air emissions, and should therefore be monitored, retorting is of particular importance.

Pollutants of major interest include nitrogen oxides, reduced sulfur compounds, hydrocarbons, and trace elements.

Data/Information Requirements -

Emissions and emission rates have not been adequately characterized for each process option under development. Variability of emissions has not been determined as a function of process option and operating conditions; upset conditions may be significant. Sampling and analytical techniques should be improved. Effects of scale-up to commercial-size operations are unknown and may present design problems. Uncertainty regarding air emissions may limit development of the oil shale industry.

Ranges of emission rates must be determined for primary pollutants and toxic compounds. Operating experience is required for pilot operations; data are required from commercial size operations for confirmation. Improved instrumentation and technology will be required for characterization of ambient concentrations and stack effluent monitoring.

Required Research -

Improved instrumentation must be developed to characterize ambient pollutant concentrations. Technology for stack effluent monitoring must be improved. Monitoring programs must be established for oil shale operations, to determine emission rates. Commercial scale operations should be monitored to confirm projections from earlier findings.

Priority - High

Problem Statement - Trace Elements

Oil shale, like all fossil fuels, contains minor elements which may potentially be mobilized and released to the environment during extraction, processing, and end use of the shale oil and its products. Because oil shale products may be substituted for coal and petroleum products, and because of the vast quantities of shale which are expected to be extracted and/or processed, the trace elements contained in oil shale are of concern. These trace elements may be released in air emissions, aqueous streams or solid wastes.

The trace elements are of concern as they may degrade air and water quality, and pose hazards to the ecosystem and human health.

At the present time knowledge is limited. Trace elements have not been fully characterized in the shale strata nor have they been adequately analyzed in air, water and solid process streams. The effects and potential for bioaccumulation and biomagnification are not fully known.

Data/Information Requirements -

Qualitative and quantitative distribution of trace elements in oil shale deposits, by location and depth.

Qualitative and quantitative analysis of trace elements in air emissions, aqueous effluents, solid wastes and leachates from oil shale operations.

Distribution and character of trace element emissions as a function of process conditions; and the effects of modifying process conditions.

Toxicity of trace elements to humans, flora and fauna.

Required Research

Qualitative and quantitative analysis of trace elments in:

- raw shales as a function of strata location and assay
- spent shales as a function of processes and process variables
- aqueous effluents as a function of processes and process variables
- air emissions as a function of processes and process variables
- potential impacts on the ecosystem, human health, air and water qualitv

Priority - High

Problem Statement - Occupational hazards from air emissions

Gaseous emissions from oil shale technologies may pose safety or health problems for occupational personnel. Current operational practices used in the petroleum and mining industries and MESA regulations are considered to be adequate for routine operations.

Non-routine exposures (e.g., upset conditions, maintenance exposure and accidents), and gaseous emissions from in situ retorting may present significant problems which must be evaluated.

Data/Information Requirements

At the present time these problems are speculative. Data must be obtained to determine if a problem does exist; and if so, what is its magnitude and severity.

Fugitive emissions must be characterized for surface and in situ operations. Potential exposure of operating personnel must be determined to evaluate associated hazards.

Occupational hazards associated with upsets, accidents and maintenance must be evaluated.

Data must be collected to properly site, design and operate oil shale operations and control equipment to reduce hazards to a minimum.

Data required for in situ operations include: strata permeability as a function of position; pressure requirements of retorting; the effect of blasting on strata permeability; mixing of in situ retort gases with ventilation gases; and explosive limits of produced gases, including suspended particulates, if any.

Required Research -

A routine monitoring program for occupational personnel must be established, to determine ocupational exposure and provide data required for epidemiological studies.

Weather, particularly wind patterns, must be monitored to provide atmospheric dispersion data for surface operations.

Shale strata should be cored to determine permeability where in situ operations may be established.

Off gas should be simulated, tested for explosion potential, and compared with off gas from in situ operations.

Priority - Medium

Problem Statement - Gases or dust in shale mine atmosphere

Particulates, shale dust, combustion gases, and to a lesser extent methane in shale mine atmospheres may pose potential health and safety hazards to mine personnel. Particulates and combustion gases may be produced by diesel-powered equipment or blasting, which may also produce shale dust levels hazardous to human health.

The potential hazard posed by methane is not thought to be significant, but should be investigated, particularly in the deeper shales. The Panel believes that the hazards posed by these air emissions can probably be adequately mitigated by proper mine design, ventilation and blasting procedures. Development and verification of adequate design, ventilation and blasting procedures for the unusually large underground shale mines must be accomplished in full-scale operations.

Data/Information Requirements -

Rates of release and concentrations of dust, methane and gaseous emissions should be determined for a full-scale underground mine operation.

Sufficient data should be obtained through monitoring emissions to develop predictive models and demonstrate proper mine design, ventilation and blasting procedures.

Required Research -

Dust and gaseous emissions should be monitored in a full-scale underground mine, including all operations which may produce the emissions, e.g., blasting, drilling, loading, transport.

The magnitude and rate of release of methane should be determined as a function of mine depth.

Predictive models should be developed to provide a basis for mine design and operation.

Potential interactions of diesel emissions and shale dust should be determined.

Blasting technologies should be developed concurrent with good mining practice, to minimize dust and emissions.

Priority - Low

Problem Statement - Nitrogen oxide emissions

Nitrogen oxide emissions from combustion of shale gas (possibly some shale oil) and blasting with ammonium nitrates/fuel oil mixture (AN-FO) may pose problems in meeting the ambient NO_x standard.

Data/Information Requirements -

The extent, magnitude, and severity of the problem is not known for each oil shale technology. Nitrogen oxide emission rates must then be determined for each technology option. Emission rates must be predicted for commercial-size operations; commercial operations must then be monitored for confirmation.

Required Research -

Rates of NO_x emisson must be monitored for each technology option. Variability of NO_x emissions must be determined. NO_x emissions should be correlated with nitrogen content in shale oil. Techniques for analyzing ambient NO_x levels need to be upgraded. Improved methods for predicting NO_x emissions from commercial-scale operations must be examined. The importance of NO_x as a precursor for ozone generation should be investigated. The capability of the oil shale industry to meet proposed EPA 3-hour emission standards should be determined.

Priority - Low

Problem Statement - Roof Control in Shale Mines

Shale mines, particularly deeper ones, must be designed to prevent injury to mining personnel and to maximize resource recovery, in addition to considering economic factors. Mining technologies available today are probably adequate to meet existing regulations. Shale mines can be properly designed when these data are available. Both ongoing and future shale mining operations should be planned to maximize their utility as underground rock mechanics and ground support laboratories. The data obtained would be very useful in developing roof control programs.

Data/Information Requirements

The data to be obtained from each mine should include: rock properties; mine design and geometrics; roof control data, e.g., sag measurements, fracture count, stress measurements, fall incidence, spalling data, and deflection vs. time measurements; hydrology effects on roof control; mining rates; vibration and seismic effects; and weathering.

Required Research -

Major areas of research include:

- modeling and simulation of oil shale mines of various designs and geometrics
- in situ monitoring of current and future mining operations
- characterization of oil shales from various mine sites to determine physical properties.

Priority - Low

Problem Statement - Characterization of treated and small volume emissions and effluents

Although considerable research has been directed toward characterizing process streams, two types of streams have received little attention: treated effluents and emissions, and small volume streams in small-scale operations. Characterization of streams after treatment is required to evaluate the effectiveness and adequacy of control technology and to develop new technologies. Characterization of small volume streams in small scale operations will aid in the evaluation of similar streams in commercial-scale plants.

Data/Information Requirements -

Flow rates and quality of all process effluents and emissions after treatment should be determined.

Required Research -

Procedures for sampling, preserving and analyzing samples should be improved and standardized. Commercial-scale modular plants should be developed to supply samples more representative of industrial operations. Effluents and emissions should be characterized after treatment by proposed control technology; stream quality should be compared with existing and proposed standards to determine control technology R&D needs.

Priority - High

Problem Statement - Contamination of groundwaters by process waters or shale leachate

Commercialization of an oil shale industry may result in returning to the ground contaminated water which has either been used in the process, or water which has filtered through raw or spent shale. Withdrawal of groundwater, or injection of water into the ground may alter the flow and chemical and physical qualities of the existing groundwater. Alternation of groundwater flow and quality may subsequently affect surface water quality and availability, thus potentially affecting flora and fauna in the region.

Data/Information Requirements -

Solubilities of shale-bearing organics and inorganics in representative groundwaters should be determined. Groundwater transport in the affected basins, e.g., Piceance Basin, should be modeled and this model verified. The effects of injecting or withdrawing water should be identified and quantified. The effectiveness of available control technology to solutes, e.g., PNA's in leachates, must be evaluated.

Required Research -

Groundwaters modeling techniques should be improved, and models for specific sites should be developed. Groundwater sampling and analytical techniques should be improved. An adequate quality assurance program should be established. Control technology must be developed and demonstrated for commercial size operations.

Priority - High

APPENDIX

A

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WORKSHOP ON THE HEALTH AND ENVIRONMENTAL EFFECTS OF OIL SHALE TECHNOLOGY

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OTHER COMMITTEE REPORTS

REPORT NUMBER	TITLE
DOE/HEW/EPA-01	Health and Environmental Effects of Coal Gasification and Liquefaction Technologies. Background Material for a Workshop.
DOE/HEW/EPA-03	Health and Environmental Effects of Coal Gasification and Liquefaction Technologies. A Workshop Summary and Panel Reports.

These and other reports of the Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies will be available from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.